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Initial Effects of Converting Army Diesel-Powered Ground Vehicles To Operate on JP-8+100 Fuel

INTERIM REPORT
TFLRF No. 347

by

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Southwest Research Institute
San Antonio, TX

Under Contract to

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13. ABSTRACT (Maximum 200 words)

The +100 additive was developed to increase the thermal stability of JP-8 aviation fuel. It has been shown that the dispersant/detergent component of the +100 additive permanently disables the water separators in fueling systems (i.e. filter/separators), potentially allowing water to enter vehicle or equipment fuel tanks. Furthermore, the additive will remove dirt and scale (previously deposited materials) from dirty fuel systems, and carry these contaminants downstream, which may quickly plug fuel filters. Some initial USAF evaluations with diesel-engine powered ground support equiment have shown only minor fuel-filter plugging problems. However, these evaluations, have been limited to flight line support equipment, which already operates on aviation-quality JP-8 fuel and is therefore at minimal risk. This project resulted in a set of data that documents the effect on fuel-borne contaminant levels resulting from operation of a previously diesel-fueled vehicle with JP-8+100 aviation fuel. The collected data illustrate that there is generally an observable increase in fuel-borne particulates during the initial circulation of JP-8+100 throughout vehicle fuel systems previously operated on diesel fuel for extended periods of time. The laboratory analyses of the collected fuel samples also show that there is generally an increase in the fuel-borne water content when a vehicle is converted to operation with JP-8+100.

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EXECUTIVE SUMMARY

Problems and Objectives: Various types of diesel-powered Army ground equipment may operate on either diesel fuel or non-aviation quality kerosene. Over time, it is possible for vehicles utilizing these fuels to accumulate contaminants in their fuel-delivery systems. There is concern that the transition from these fuels to JP-8+100 may result in fuel-injection system problems due to the JP-8+100 carrying water or debris through the fuel system filter/separator. Determination of any potential risks associated with the use of JP-8+100 in diesel-powered ground vehicles would allow proper preventative measures to be developed, thereby minimizing the impact of converting at-risk vehicles to JP-8+100.

Importance of Project: This project determined the likelihood and severity of any increase in fuel-borne contaminants due to the introduction of JP-8+100 into vehicles previously operated on diesel fuel for extended periods of time.

Technical Approach: Several diesel-powered vehicles obtained from a local Army reserve unit were tested using commercially available particle-counting equipment. Fuel-borne particle counts were recorded for each vehicle, first utilizing the original diesel fuel then switching to JP-8+100. Data collected from these experiments were then compared for any increase or decrease in fuel-borne contaminants resulting from the introduction of JP-8+100 to the fuel system. Fuel samples collected from each test case were also evaluated in the laboratory for water and gravimetric particulate content.

Accomplishments: This project resulted in a set of data that documents the effect on fuel-borne contaminant levels resulting from operation of a previously diesel-fueled vehicle with JP-8+100 aviation fuel. The collected data illustrate that there is generally an observable increase in fuel-borne particulates during the initial circulation of JP-8+100 throughout vehicle fuel systems previously operated on diesel fuel for extended periods of time. The laboratory analyses of the collected fuel samples also show that there is generally an increase in the fuel-borne water content when a vehicle is converted to operation with JP-8+100.

Military Impact: The results of this project show that some diesel vehicles may be at risk for increased fuel-injection system contamination and wear when initially exposed to JP-8+100 aviation fuel.

FOREWORD/ACKNOWLEDGMENTS

This work was performed by the U.S. Army TARDEC Fuels and Lubricants Research Facility (TFLRF) located at Southwest Research Institute (SwRI), San Antonio, Texas, during the period December 1998 through October 1999 under Contract No. DAAK70-92-C-0059. The work was funded and administered by the U.S. Army Tank-Automotive RD&E Center, Petroleum and Water Business Area, Warren, Michigan. Funding was administered by Mr. Luis Villahermosa (AMSTA TR-D/210) serving as the TARDEC contracting officer's representative and project technical monitor.

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ACRONYMS & ABBREVIATIONS

ASTM	American Society for Testing and Materials
HMMWV	High Mobility Multipurpose Wheeled Vehicle
JP-8	Jet Propellant 8
SwRI	Southwest Research Institute
TARDEC	U.S. Army Tank Automotive Research, Development and Engineering Center
TFLRF	U.S. Army TARDEC Fuels and Lubricants Research Facility
USAF	U.S. Air Force

1.0 INTRODUCTION AND BACKGROUND

The +100 additive for JP-8 aviation fuel was developed as a solution to hot surface fuel deposition problems that can occur in certain types of aircraft turbine engines currently used by the U.S. Air Force (USAF). It has been shown that the dispersant/detergent component of the +100 additive permanently disables the water separators in fueling systems (i.e. filter/separators), potentially allowing water to enter vehicle or equipment fuel tanks. Furthermore, the additive will remove dirt and scale (previously deposited materials) from dirty fuel systems, and carry these contaminants downstream, which may quickly plug fuel filters. Some initial USAF evaluations with diesel engine powered ground support equipment have shown only minor fuel-filter plugging problems. However, these evaluations have been limited to flight line support equipment, which already operates on aviation-quality JP-8 fuel and is therefore at minimal risk.

With the USAF use of JP-8+100, and the military's move toward using a single type of fuel for all combat and support vehicles, the U.S. Army may intentionally or accidentally use the fuel. A test conducted by General Dynamics Land Systems on an AVDS-1790 engine raised the concern that initial usage of JP-8+100 in fuel systems that previously used diesel fuel may result in a large concentration of small debris passing through fuel filters and into the fuel-injection system. Since diesel-powered Army equipment may have operated on either diesel fuel or non-aviation quality kerosene for extended periods of time, there is concern that the use of JP-8+100 in place of these lower quality fuels may result in engine fuel injection pump and fuel injector damage. It was therefore proposed to conduct a preliminary study to assess the likelihood and severity of problems that may occur when at-risk Army ground equipment is converted to operate on JP-8+100.

2.0 OBJECTIVES AND APPROACH

Past studies have concluded that particulate contamination measuring 5µ to 15µ poses the largest threat of wear-related damage to fuel-injection-system components (1).* There is concern that the +100 additive disperses fuel-borne particulates so effectively that a "particle cloud" is formed, consisting of small

*Underscored numbers in parentheses indicate references at the end of the document.

particles suspended in high concentration. Although these small particles would normally be passed through the fuel-filtration system anyway, the rapid-cleaning effect of the JP-8+100 may increase the concentration levels to a point that could threaten fuel-injection system durability. Water that is present in fuel tanks from condensation or contaminated fuel supplies could also conceivably pass through the water separator/filter due to the anti-coalescent nature of the +100 additive. This drastically reduces the lubricity of the fuel, causing accelerated wear in close-tolerance components.

The goal of this project was to perform a series of experiments that will produce data illustrating how JP-8+100 affects the levels of fuel-borne particulates, and how it impacts the filtration capability of diesel-powered vehicle fuel systems. In order to attain this goal, a dynamic method of monitoring the population of fuel-borne particulates was necessary. Laser-optic, particle-counting devices were utilized that are capable of measuring and recording the size distribution of fluid-borne particles by interpreting the pattern of scattered light produced when an object passes through a narrow laser beam. Two different models of particle counters were used in this project. The first is a Vickers model 130 portable counter (Figure 1) capable of collecting data in the field and downloading it to a computer. The second is a Met One model (Figure 2), which requires a supporting PC for operation and data storage.

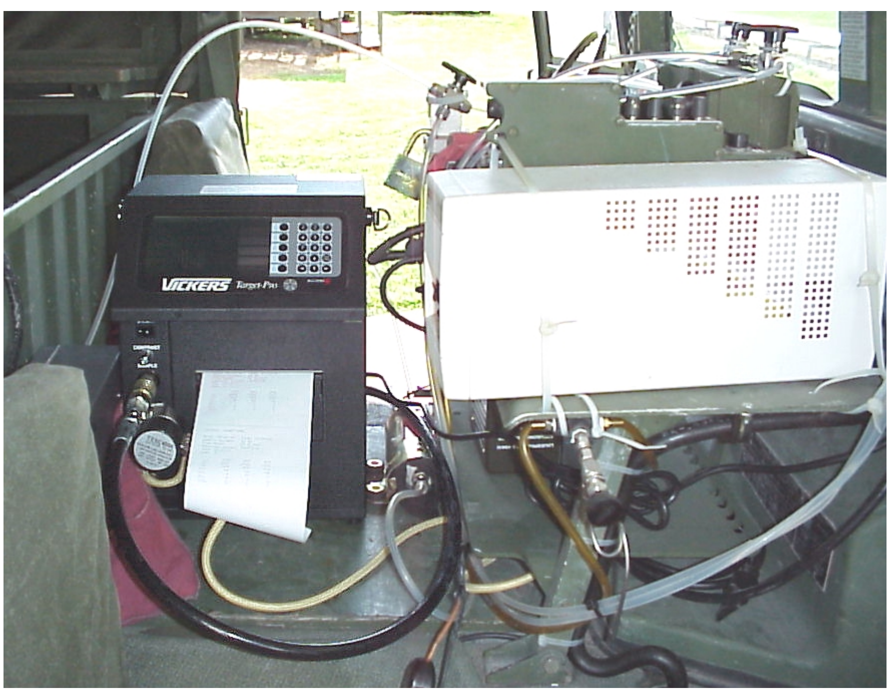


Figure 1. Vickers Portable Particle Counter Installation

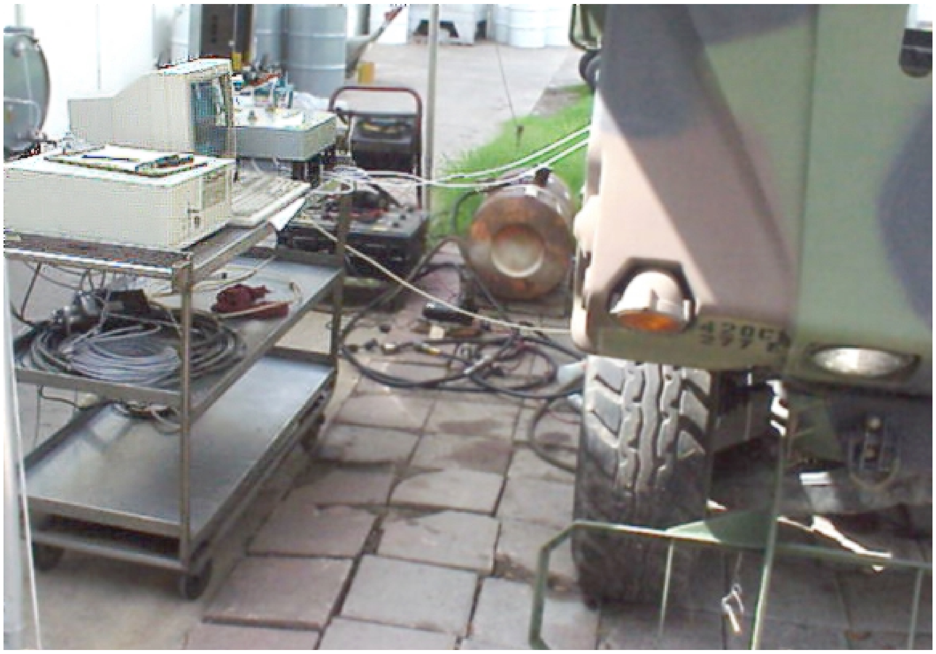


Figure 2. Met One Particle Counter Installation

The approach used to observe the particulate concentration levels encountered during vehicle operation was to install the particle counter "on-line" with the fuel-delivery system. By using various fittings and valves, sampling lines were used to tap into the before- and after-filter sides of the fuel supply line, then routed to the particle counter. The return line from the particle counter was connected to the vehicle's fuel return line. In this manner, the operator could obtain a representative sample from either side of the fuel filter by merely closing and opening the appropriate valves. Additional valves were also installed in each sampling line to facilitate the extraction of bottled fuel samples for laboratory analysis. It was also important to eliminate exposure of the test vehicle's engine to any contaminants introduced into the fuel during these testing procedures. For tests using JP-8+100 and requiring a running engine, an auxiliary tank was connected to supply clean diesel fuel for the engine. This exposed the vehicle's fuel tank, supply lines and filter to the JP-8+100, while assuring that no contaminants reached the fuel-injection system components. The exact configuration used for each test vehicle is detailed by schematic diagram in *Section 3*. The particle-counting procedure was first performed with each vehicle stationary to simulate refueling conditions encountered at idle. Some vehicles were then also driven while simultaneously collecting data, so that a comparison could be made between the at-rest particle concentration levels and those experienced from agitation during operation.

All of the vehicles tested in this experiment were obtained from the 277th Engineer Co., ECS No. 2, and US Army Reserve Unit San Antonio, TX. The vehicles used were selected based on various factors, including service density of the vehicle, availability, and fuel-system condition. The goal was to select vehicles that had long-term exposure to only diesel fuel, thereby providing a relatively severe test of the effects of JP-8+100 when a sudden change in fuel type occurs. The 277th Engineer Co. employs mostly utility and construction type vehicles such as HMMWVs, heavy trucks, and earth-moving equipment. Since the HMMWV is the most common vehicle used in the military, and runs a high risk of being exposed to JP-8+100, it was the focus of the experiment. A five-ton truck-tractor was also selected for testing because the fuel tanks are made of steel and prone to corrosion by fuel-system contaminants, thereby providing a possible worst-case test condition.

3.0 PROCEDURE AND RESULTS

Because this type of dynamic study of particulate contamination in vehicle fuel systems was a new endeavor for the TARDEC Fuels and Lubricants Research Facility (TFLRF), each subsequent experiment underwent changes in procedure as knowledge was gained and methods were developed. However, there is a basic procedure used as the general guideline for all tests performed. Details concerning procedural changes for each vehicle will be explained separately from the basic testing procedure outlined below.

Basic Testing Procedure For All Vehicles

1. **Visual Tank Inspection:**

   The vehicle tanks were inspected with a borescope to determine the condition of the tank and fuel before testing. These conditions were noted for later reference.

2. **Installation of Particle Counting Hardware:**

   The particle counter(s) were connected to the vehicle fuel system at locations before and after the vehicle fuel filter. For initial tests using the original diesel fuel, no other changes were made to the existing fuel supply and return system. Testing was conducted using the fuel filter already in service on the vehicle in order to simulate the conditions that could be encountered by a unit refueling in the field.

3. **Baseline Particle Count Testing of Original Diesel Fuel:**

   Baseline data was obtained for the non-agitated condition (stationary vehicle) with the vehicle fuel system recirculating fuel to the tank. Readings from before- and after-filter locations were recorded.

4. **Agitated-Condition Testing of Original Diesel Fuel: (Optional)**

   The vehicle was then driven over a determined off-road course on Southwest Research Institute (SwRI) grounds to agitate the fuel in the tank and facilitate suspension of any particulates existing in the original fuel. A sequence of particle count readings were taken for the before- and after-fuel-filter sample locations to provide a baseline for the agitated diesel fuel condition. Preliminary testing showed that after switching between sample lines with the Vickers counter, a minimum of three consecutive samples may be needed to clear the line and obtain a representative reading for the active sample line.

5. **Collection of Diesel Laboratory Samples:**

   Upon completion of particle-count testing, samples of the diesel fuel were drawn from the before- and after-filter sample lines. One liter of fuel was collected for each case. These samples were later analyzed for water and gravimetric particulate content.

6. **Removal of Diesel Fuel from Vehicle Tank:**

   After testing with the original vehicle fuel was completed, the diesel was removed from the tank. During this procedure, it was most important to prevent disturbing or accidentally removing any sediments or contaminants present along the walls or bottom of the tank. Removal of the fuel was accomplished by connecting a small electric pump in series with the vehicle fuel line and pumping the diesel into a storage container. This fuel was saved to refill the tank after testing was completed.

7. **Conversion of Vehicle for JP-8+100 Tests:**

   The test vehicle was converted to operate on an auxiliary fuel tank, separating the engine from the vehicle fuel delivery and return systems. This protected the engine against possible contaminants resulting from the addition of the JP-8+100 fuel. The only vehicle components that were exposed to the JP-8+100 were the fuel tank, fuel supply and return lines, fuel pump, and fuel filter.

8. **Addition of the JP-8+100 Fuel:**

   Pre-blended JP-8+100, obtained from Kelly Air Force Base in San Antonio, TX was added to the vehicle fuel tank up to approximately ¾ full.

9. **Testing with the JP-8+100 fuel:**

   - Upon starting circulation of the JP-8+100 fuel, continuous readings were taken using the particle counter(s). These particle-count readings were initially taken in a non-agitated condition with the vehicle being stationary. Following the stationary data collection, the vehicle may have been driven in the same manner as described in step 4 in order to collect agitated-state readings.
   - Immediately following the particle-counting procedure, fuel samples were extracted from the before- and after-filter sample lines for laboratory analysis of water and particulate content. Approximately 1 liter was taken from each point. The results of these analyses will be compared to the original diesel fuel samples collected in step 5.

10. **Drain and Clean Fuel Tank:**

    The JP-8+100 was drained from the vehicle fuel tank, and the tank was flushed with diesel if necessary. A new fuel filter was also installed.

11. **Return Vehicle to Original Condition:**

    All test equipment was then disconnected from the vehicle, and the auxiliary fuel supply system was removed. After refueling with diesel, the vehicle was allowed to run at idle for a length of time and inspected for possible leaks or other problems. A technician verified that all systems were functioning properly before returning the equipment to the Army Reserve base.

3.1 CS300 HMMWV

This was the first vehicle to be tested and provided experience in using the new equipment as well as developing the testing methods. Testing of this vehicle utilized the Vickers portable particle counter, which was installed as shown in the fuel system schematic illustrations. As with all of the HMMWVs, the engine-driven diaphragm pump was the primary means of circulating fuel from the vehicle tank, through the filter, and back to the tank. The Vickers particle counter requires a minimum line pressure of 30 psi to operate properly, therefore an auxiliary electric pump was used to provide this boost on the counter inlet side. A borescope inspection of the vehicle fuel tank indicated some buildup of residue along the bottom and walls. The diesel fuel was clear, but some floating debris was evident. The procedure used for this HMMWV followed the basic testing procedure outlined previously, with the addition of the following details.

3.1.1 Baseline Idle Diesel Testing

Using the configuration shown in Figure 3, baseline diesel testing began with particle-count readings being taken immediately upon startup of the engine. The engine was run at idle speed during the stationary baseline testing, providing circulation of the fuel. In order to observe any changes occurring in the particle counts on either side of the fuel filter, readings were taken from both sampling lines in an alternating manner. Several readings would be taken from one line until it appeared that a representative value had been reached, then, switching to the other line, the process was repeated. Readings were taken in this manner for about three hours, and the data was downloaded for later examination.

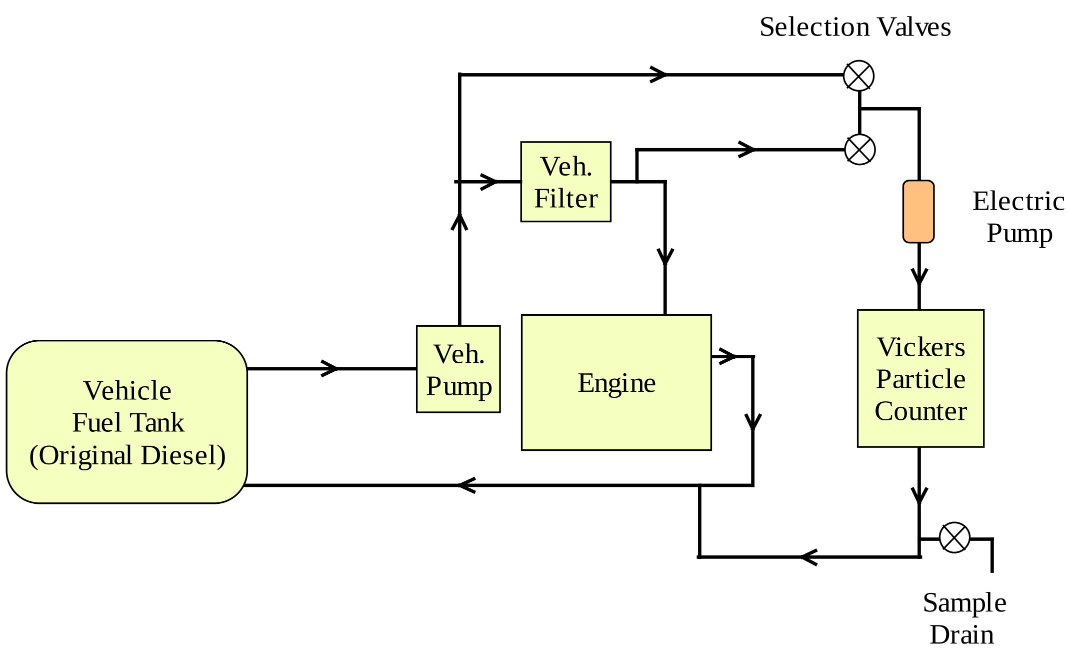


Figure 3. Vickers Particle Counter: HMMWV Original Diesel Test Configuration

3.1.2 Agitated-Condition Diesel Testing

The day after completing the diesel idle test, the agitated-condition testing for the diesel fuel began. The course for all road-tested vehicles consisted of service roads located on SwRI grounds. The slight roughness of these roads, combined with the stiff suspension of the Army vehicles, provided ample agitation of the fuel-tank contents. The road test began with pre-driving idle data being recorded in order to view the effect of the transition from a non-agitated state to rough driving conditions. When sufficient data had been collected at idle, the vehicle was put into motion. While one operator drove the vehicle around the course, another acquired and monitored data using the portable particle counter. Again, readings were taken from the before- and after-filter lines in an alternating manner. Data was collected for approximately two hours before terminating the test. Upon returning to the shop location, bottle samples of the fuel were collected as mentioned in the procedure outline.

3.1.3 JP-8+100 Testing

The HMMWV was then converted to the fuel system configuration of Figure 4 in order to perform the JP-8+100 testing. Since the Vickers particle counter is capable of recording data from only one sample line at a time, it was decided to take readings of the JP-8+100 test from primarily the after-filter fuel flow. This would then reveal the particulate concentration levels of fuel entering the engine under normal operating circumstances.

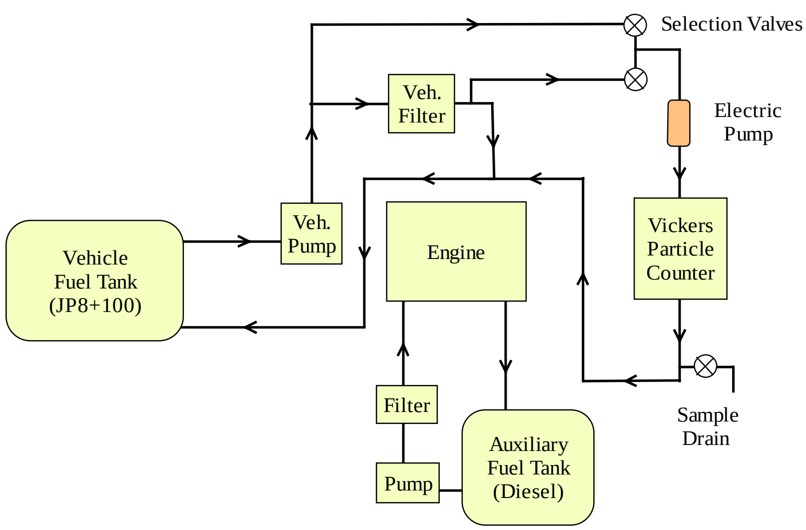


Figure 4. Vickers Particle Counter: HMMWV JP-8+100 Test Configuration

Data was collected after the initial engine startup for approximately one hour at engine idle speed until it appeared that the particle counts had leveled out. Upon reaching this point, the vehicle was then taken out on the road course to gather the agitated JP-8+100 data. This data was collected until it appeared that the counts had stabilized, and the vehicle was then returned to the shop.

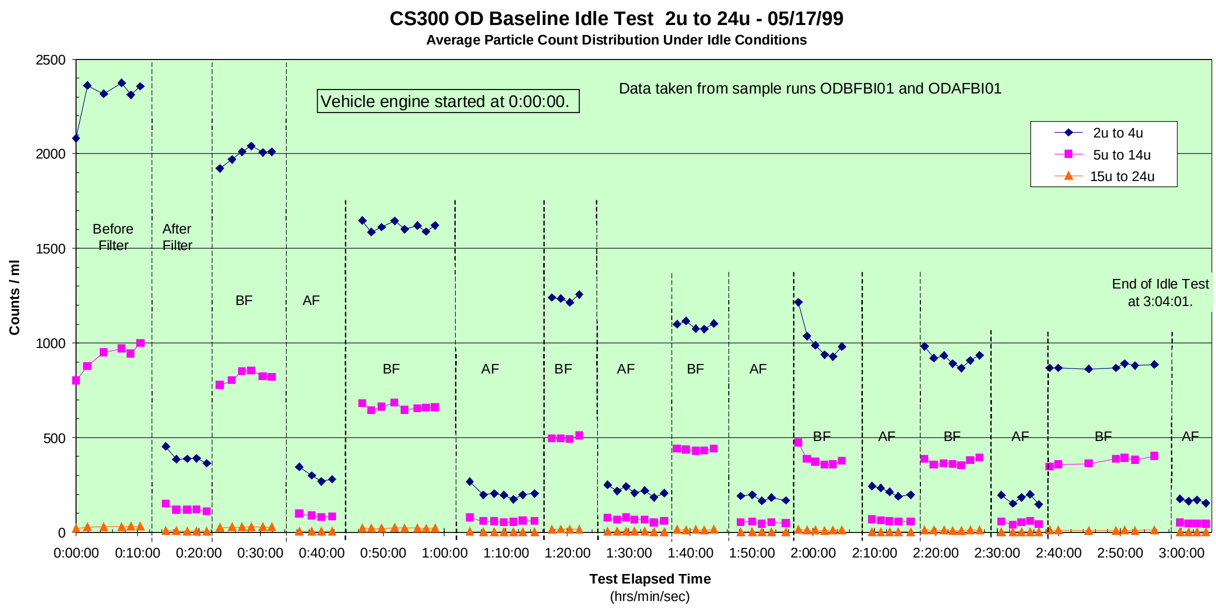
After the test was completed, in the process of downloading the data from the particle counter memory, a power failure occurred to the particle counter, causing all of the collected JP-8+100 data to be lost. Some hand-written notes taken during the idle test as a means of monitoring the results are the only record remaining of this portion of the CS300 JP-8+100 testing. Nevertheless, this limited amount of data still has value and is presented in graph form in Appendix A, Figure 3.

<u>3.1.4 Discussion of Results</u>

3.1.4.1 Idle Test

The baseline idle diesel data of Figure 5 illustrate the trend of the original diesel particulate concentration levels to steadily decrease over time as the vehicle idles while stationary. On the before-filter side, the concentration of particles is very high at engine startup. As the fuel circulates, particles apparently settle out of the fuel stream. Some particles may be collected by the fuel filter, but the experience gained in these tests suggests the particles are still free in the fuel system. If the vehicle is left undisturbed for a long period then restarted, the particle counts return to the previously high levels, indicating that they are still in the fuel circuit and not trapped in the filter. The after-filter counts also decrease over time, but they start at a lower level than the before-filter side. A large percentage of the particles in the diesel fuel seem to be stopped by the filter. Even small particles (2µ to 4µ), which are considered to be below the effective range of the filter, are significantly reduced in quantity. After a few hours of circulating at idle, count levels for the before- and after-filter samples plateau and appear to stabilize.

The tendency of particles to “drop out” rather rapidly on the before-filter side under steady idle conditions leads to a corresponding decrease in the calculated filtration efficiency, since the ratio of before-filter to after-filter particles gradually decreases. However, the filtration *effectiveness* remains fairly steady, even increases, since the number of particles passing through the filter either remains the same or decreases with time. The concept of filtration effectiveness versus efficiency is important to consider when dealing with lower concentration levels. For example, before-filter readings of 5/ml, and 40/ml combined with an after-filter reading of 1/ml would calculate to efficiencies of 80% and 98%, respectively. However, effectiveness is the same in both cases since the after-filter concentration remains unchanged.



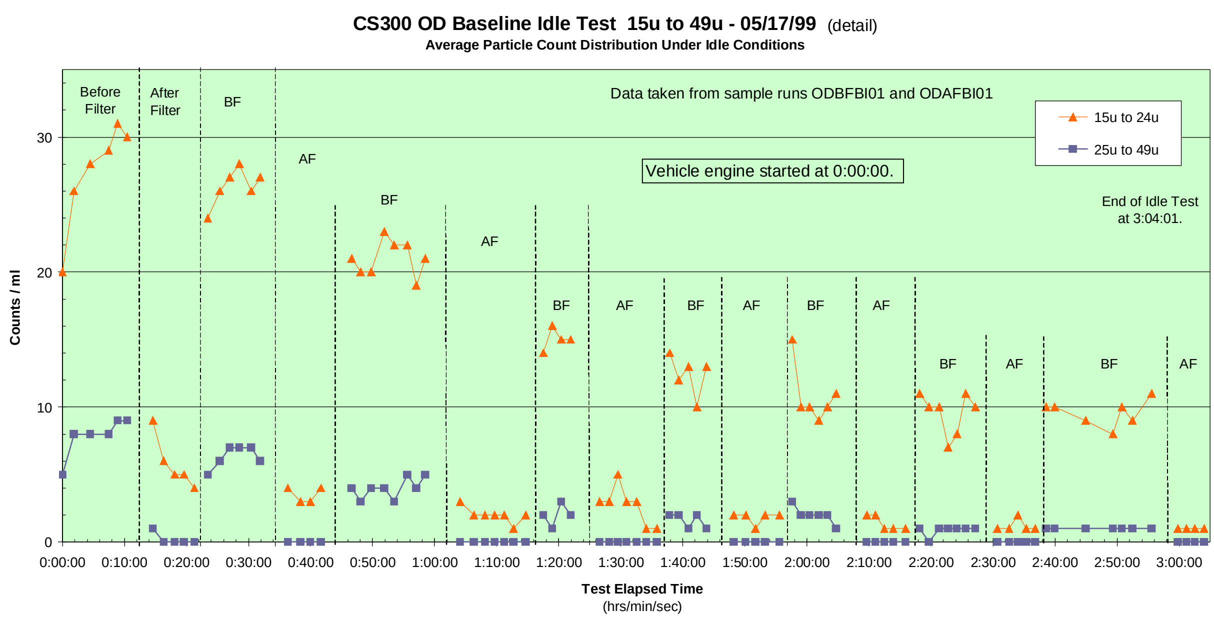


Figure 5. CS300 HMMWV Diesel Idle Test Data

As mentioned previously, the JP-8+100 data collected by the particle counter was lost and only some hand-written data was saved. These data can be used in a partial comparison with the diesel test data. Although the data from the hand-written notes had no time-stamp noted, it is known that each sample run requires approximately 1.5 to 2 minutes to complete. This allowed some general comparisons for the estimated times during both tests. This data, presented in Figure 6, show that the concentration level of 5µ to 14µ particles increases for a short time after circulation of the JP-8+100 begins. From sample #6 to #25, approximately 10 to 40 minutes after startup, there are 5µ to 14µ particle counts ranging from 78/ml to 239/ml (disregarding the spike at #25). This same time period on the diesel graph yields counts ranging from 80/ml to 120/ml, indicating an increase in particles with the JP-8+100. The 5µ to 14µ counts then appear to diminish after sample #25, and the JP-8+100 counts are actually less than those of the diesel fuel after almost an hour, except for one spike of 250/ml at sample #35. Beginning at JP-8+100 sample #22, the 15µ and larger particles seem to increase in frequency for a short time, cycling between zero counts and highs of 25/ml to 54/ml. The same approximate time frame on the diesel graph yields counts of only 1 to 4 per milliliter. This trend continues until the JP-8+100 idle test is terminated after sample #36, or approximately one hour of running time.

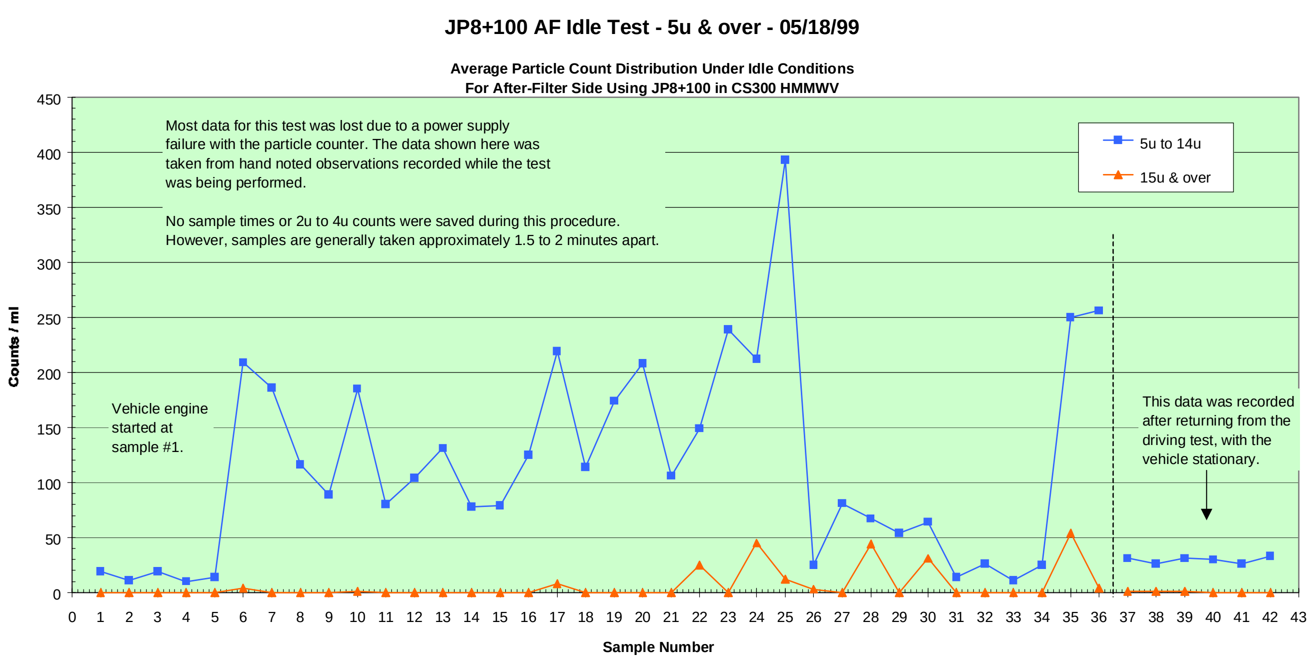


Figure 6. JP-8+100 AF Idle Test - 5µ and Over

3.1.5 Idle Test Conclusions

The data acquired from this vehicle demonstrate that there is a period of increase in fuel-borne particles entering the fuel-injection system upon conversion to JP-8+100 fuel. Much of this particulate matter falls into the potentially harmful size range of 5μ to 14μ.

3.1.6 Road Test

The CS300 diesel road test data in Appendix A, Figures 2a and 2b, show that when the fuel undergoes agitation, the concentration levels of all particle sizes increase and do not drop drastically with time, as long as the agitation level remains constant. These concentrations are substantially higher than the stabilized values of the idle test attained after a few hours of constant running. From the data plot, it can also be seen that when the vehicle makes a transition to a smoother street surface, there is a decrease in the particle counts. Since the data from the JP-8+100 road test was lost, no comparison can be made as to the effects of the fuel change in this vehicle.

3.2 CS500 HMMWV

The Vickers portable counter was again used for this experiment using the same installation as the CS300 HMMWV. Testing of this vehicle was completed with none of the previously encountered equipment failures or problems. A borescope inspection of the fuel tank revealed a condition similar to that of CS300. There was a noticeable buildup of contaminants along the tank walls, with some debris suspended in the fuel. The experimental procedure used for this HMMWV followed the same basic format as the CS300, with the exception of the following changes:

3.2.1 Baseline Idle Diesel Testing

The major difference between the procedure used with this HMMWV and the CS300 was in the diesel idle testing. At the time of this test, various methodologies were explored, and an alternate means of comparison was used. The thought was that a comparison should be made between the "stabilized" particle count values of diesel and JP-8+100 obtained after several hours of running. This would then show the difference in particulate levels existing well after the vehicle was refueled and had the opportunity to fully circulate the new fuel.

Upon initial sampling of the fuel during preparation of the vehicle, it was found that the original diesel contained much higher particulate concentration levels than the previous HMMWV. It would therefore take much longer for the counts to settle after initial startup. Because of the portable particle counter's limited memory for data storage, the vehicle was allowed to run for a few hours before collecting the data. This would allow time for the readings to near the stabilization region and save memory space for more of the desired data. With this in mind, the vehicle engine was started and left to idle for nearly three hours before the first diesel readings were recorded. Data was then recorded for nearly four hours before terminating the test.

3.2.2 Agitated-Condition Diesel Testing

Immediately after collecting the diesel idle data, the road test was performed for the diesel fuel. As with the previous HMMWV, readings were taken in an alternating manner between the before- and after-filter lines. This process continued for approximately one hour until the test was ended.

3.2.3 JP-8+100 Testing

The JP-8+100 test procedure followed the same format as that of CS300, except the data was not lost. Data from the after-filter line was recorded for approximately one hour at idle before beginning the road test. The road test portion of the experiment also took about an hour, with readings taken from both the before- and after-filter lines. Graphs of the data collected for these tests can be found in Appendix A.

3.2.4 Discussion of Results

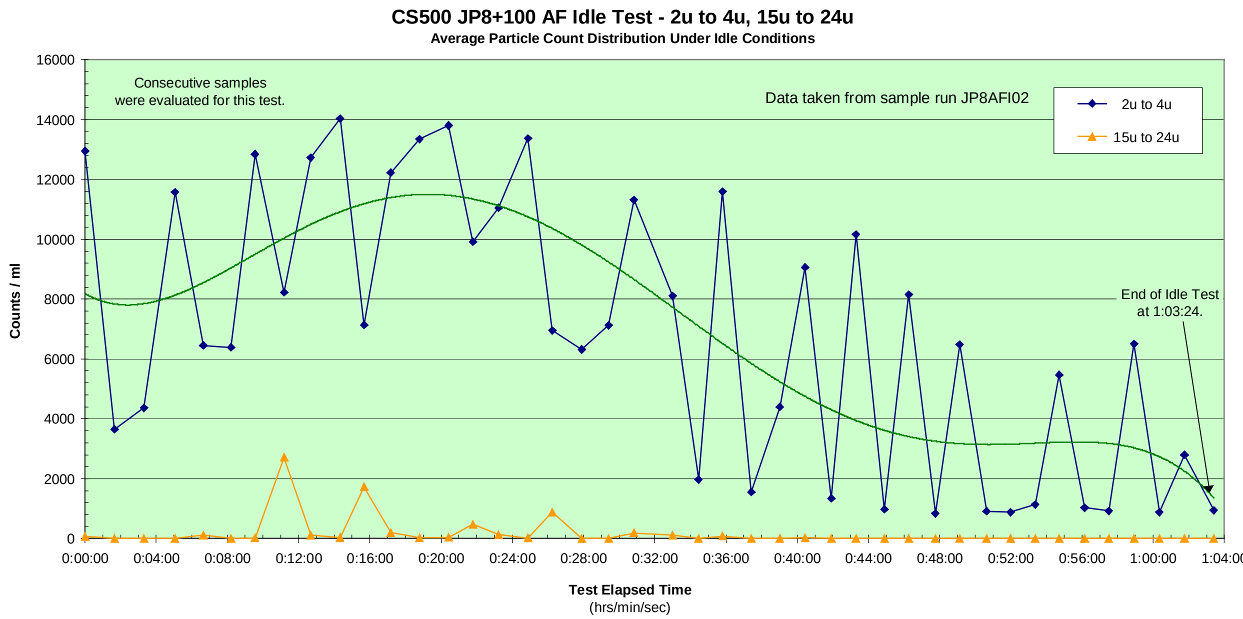
3.2.4.1 Idle Test

In retrospect, the method used to collect the idle diesel data for this vehicle provided no correlation between the time frames of the diesel and JP-8+100 idle tests. This makes it impossible to overlap the diesel and JP-8+100 data to show a direct comparison. However, by using trends observed in the CS300 HMMWV data, a general comparison can be made between the CS500 diesel and JP-8+100 idle results.

The CS300 diesel baseline idle data demonstrates that the rate of decrease in before-filter particulate concentration levels is fairly linear during the initial period after vehicle startup. With the assumption that this is true for all cases, this observation can be applied to the CS500 data, and startup concentration level values can be extrapolated for the before-filter diesel. Then, with the before- and after-filter data that was collected, an approximate filtration ratio can be calculated for each particle size range, allowing determination of the possible after-filter concentrations at startup. This will then provide a means of comparison for any increase in contaminant levels caused by the JP-8+100.

This process, and the diesel idle data in Appendix B, Figures 1a-c, produces conservative estimated filtration ratios of 10:1 for the 2μ to 4μ particle range and 13:1 for the 5μ to 14μ range. The 15μ and larger particles are minimal and appear to experience a filtration ratio of up to 10:1, but a conservative filtration ratio of 6:1 is assumed to ensure that the after-filter counts are not underestimated. Extrapolation along the before-filter diesel lines then produces counts of 12000/ml for 2μ to 4μ, 2500/ml for 5μ to 14μ, and 25/ml for 15μ and larger at vehicle startup. These assumptions provide after-filter concentrations of 1200/ml for 2μ to 4μ particles, 190/ml for 5μ to 14μ, and 4/ml for 15μ and larger in the original diesel fuel at initial startup.

Looking at the JP-8+100 after-filter data of Figure 7, the corresponding initial concentrations of these particle ranges can be found and a comparison made. Discounting the very first reading at 0:00:00 in order to be conservative, the initial readings are 3650/ml for 2μ to 4μ, 365/ml for 5μ to 14μ, and 4/ml for 15μ and larger particles. It is noted that even when using these conservative estimates, there is a substantial increase in the 2μ to 14μ concentration levels immediately upon startup. The mean concentration level of these particles in the JP-8+100 then continues to increase until about 20 minutes after startup. The 15μ and larger concentration level is a bit slower to increase, but after six minutes, a surge of 112 counts/ml is noted with following surges reaching up to a maximum of 2710/ml. Since it is known that the diesel fuel particle levels will steadily decrease after startup, the difference in concentration levels will dramatically increase as the JP-8+100 levels increase. Even if it is assumed that the initial estimated diesel counts will remain steady at 1200/ml, 190/ml, and 4/ml for the 2µ to 4µ, 5µ to 14µ, and 15µ and larger, respectively, the concentration levels in the JP-8+100 increase by up to 1050% for the 2µ to 4µ particles, up to 6600% for the 5µ to 14µ particles, and up to 67400% (2700 counts per milliliter more) for 15µ and larger.



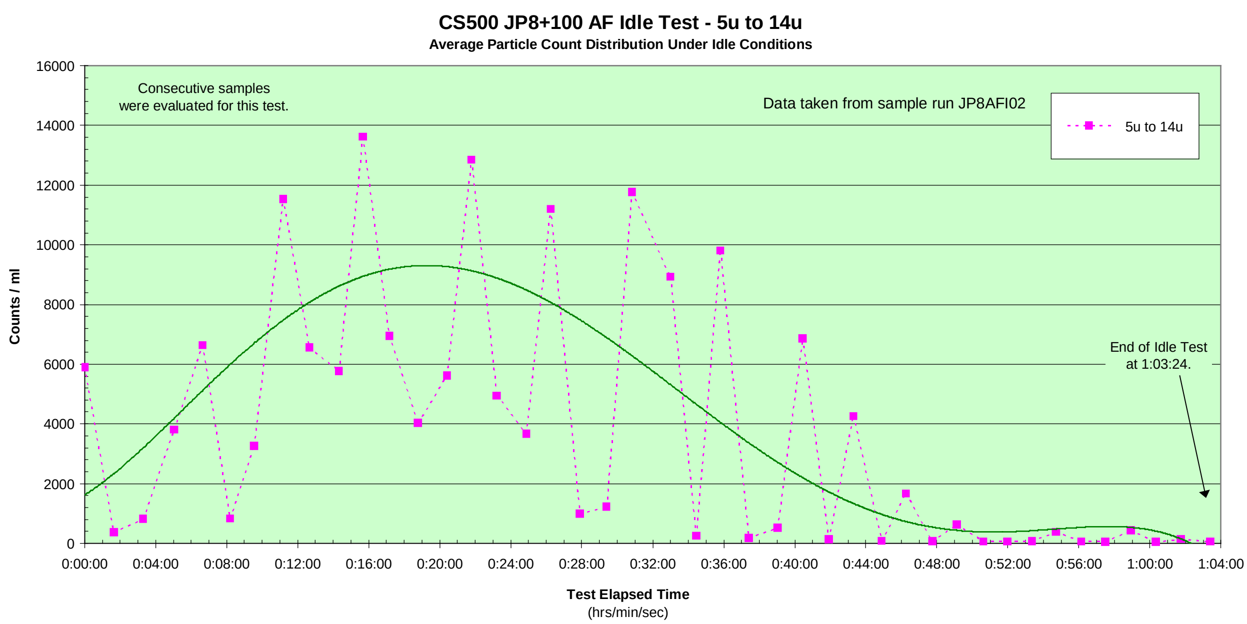


Figure 7. CS500 HMMWV JP-8+100 After-Filter Idle Test Data

3.2.4.2 Idle Test Conclusions

The results of this comparison indicate that the introduction of JP-8+100 either results in lower filtration effectiveness or causes particulate matter to be washed off of the filter and into the engine-bound fuel stream. From the data presented, it can be seen that a large percentage of the recorded particles fall into the 5μ to 14μ size range. As mentioned earlier, particles in this category have been determined to pose the largest risk of premature wear in diesel engine fuel-injectors and pumps.

3.2.4.3 Road Test

Comparing the road test data with the idle data provides some insight as to the effect of constant agitation on the particle-concentration levels and filtration efficiency. As with the CS300 results, the CS500 diesel fuel road test data reveals that the constant agitation provided by driving the vehicle helps maintain the particle counts at a fairly steady level on the before-filter side. The maintained concentration level is also higher than the stabilized values at idle conditions. However, the after-filter side does not appear to be significantly affected by the constant motion of the vehicle and fuel (Appendix B, Figure 2c). This is illustrated by the fact that the "stabilized" idle test counts and the road test after-filter counts remain about the same for this case.

Since the particle counter was dedicated to the after-filter side during the JP-8+100 idle and idle-to-road test transition, no examination can be made of the before-filter concentration levels during these periods. However, before-filter data was collected later in the road test segment. Figure 8 shows that the JP-8+100 after-filter road test data for this vehicle continues where the idle test data of Figure 7 ends, illustrating the transition from a stationary to a dynamic state.

The data plot shows that within 15 minutes of starting the road test, the particle counts on the after-filter side have basically reached a stable level. The next group of data between 1:39:00 and 1:49:00 elapsed time again shows that the after-filter counts eventually settle to the same range as before. This can then be regarded as the stabilized concentration level for the JP-8+100 after-filter agitated condition.

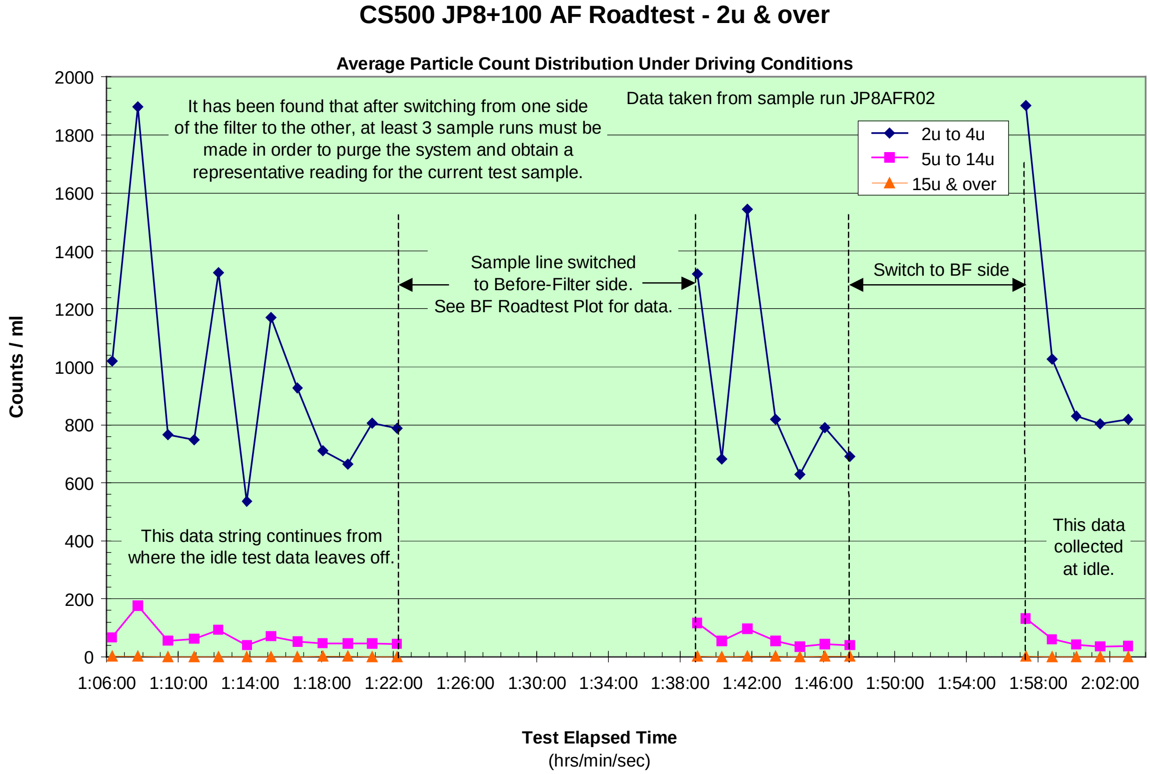


Figure 8. CS500 HMMWV JP-8+100 After-Filter Road Test Data

The JP-8+100 before-filter road test data also demonstrates that a basically stable concentration level exists in the unfiltered fuel during the agitated state. It appears that either the increased fuel circulation rate due to the higher fuel pump speed, the effect of constant agitation, or both, contribute to the fuel-borne particle counts quickly reaching a steady level. Comparison of these before- and after-filter particle counts reveals approximate filtration efficiencies of 94% for the 2μ to 4μ range, 98% for the 5μ to 14μ range, and 97% for the 15μ and larger particle range (see Appendix B, Figures 4a-d).

3.2.4.4 Road Test Conclusions

The results of the agitated-condition testing with this vehicle demonstrate that there is an increase in the particle concentration levels of the unfiltered JP-8+100 compared to the unfiltered diesel while the vehicle is in motion. However, the increase in concentration of particles passing through the filter seems to be limited to the smaller 2μ to 4μ range. Comparison of the "stabilized" 2μ to 4μ JP-8+100 after-filter counts shows levels that are 3 to 4 times larger than the original diesel fuel. This suggests that although the use of JP-8+100 increases the number of particles suspended in the fuel, the effectiveness of the filter is not hindered in the larger size ranges that are deemed most harmful to engine components.

3.3 CS522 5-Ton Truck

In order to see the effect of JP-8+100 in a corroded metal fuel tank, a 5-ton truck-tractor was selected for testing. The steel fuel tank of this vehicle was visibly rusted inside and out, as evidenced by a preliminary borescope inspection. The Vickers portable particle counter was again utilized, and was installed as illustrated in the diagrams. Due to a malfunctioning electrical generator on the vehicle, weak batteries caused interruptions to the testing process. The procedure for this vehicle follows the same format as the CS500 HMMWV, with the addition of the following details.

3.3.1 Baseline Idle Diesel Testing

The baseline idle diesel test was actually conducted twice because of a power failure caused by the low battery condition. The goal was to perform the diesel road test immediately after the idle test. However, since the power failure interrupted this schedule, the test was repeated the following day. As with the CS500 HMMWV test, it was later realized that the method used to collect the baseline diesel data would not allow a direct comparison to the JP-8+100 data due to the fact that the truck was allowed to idle for a length of time before starting the diesel test particle counts. However, the data from this test is still of interest because it provided some insight about using JP-8+100 in a corroded environment. Figure 9 shows the fuel-system configuration used for the idle and agitated-condition diesel testing procedures.

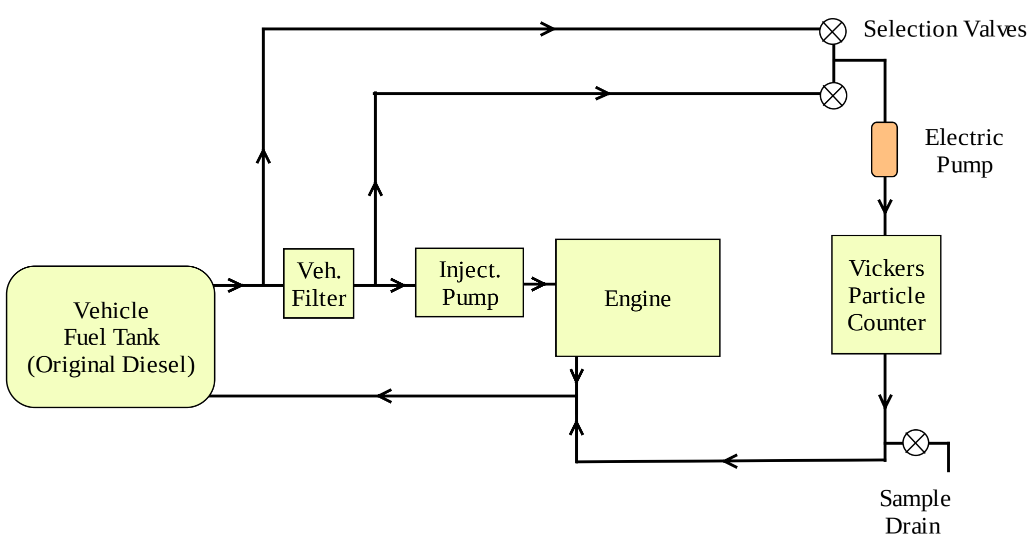


Figure 9. Vickers Particle Counter 5-ton Truck Original Diesel Test Configuration

3.3.2 Agitated-Condition Diesel Testing

After completing the second diesel idle test, the road test was completed without incident. The collected data documents the transition from smooth street conditions to the rougher roads chosen for the agitation testing. As with the previous road testing, data was collected alternately between the before- and after-filter sample lines. Data was collected with the vehicle in motion for nearly 50 minutes.

3.3.3 JP-8+100 Testing

Data for the JP-8+100 idle testing was collected similarly to the previous HMMWVs, except the JP-8+100 was not added to the fuel tank at the outset of the experiment. It was also unnecessary to actually run the engine for this test, since the JP-8+100 was circulated using auxiliary electric pumps, as illustrated in Figure 10. Almost all diesel fuel was removed from the vehicle tank, leaving enough to keep the supply pickup tube submerged, and particle count readings were collected for 38 minutes to provide an initial baseline. JP-8+100 was then added up to ¾ full, while particle count readings continued. The purpose of this procedure was to monitor the effect of suddenly introducing JP-8+100 to the fuel tank while the diesel fuel was being circulated.

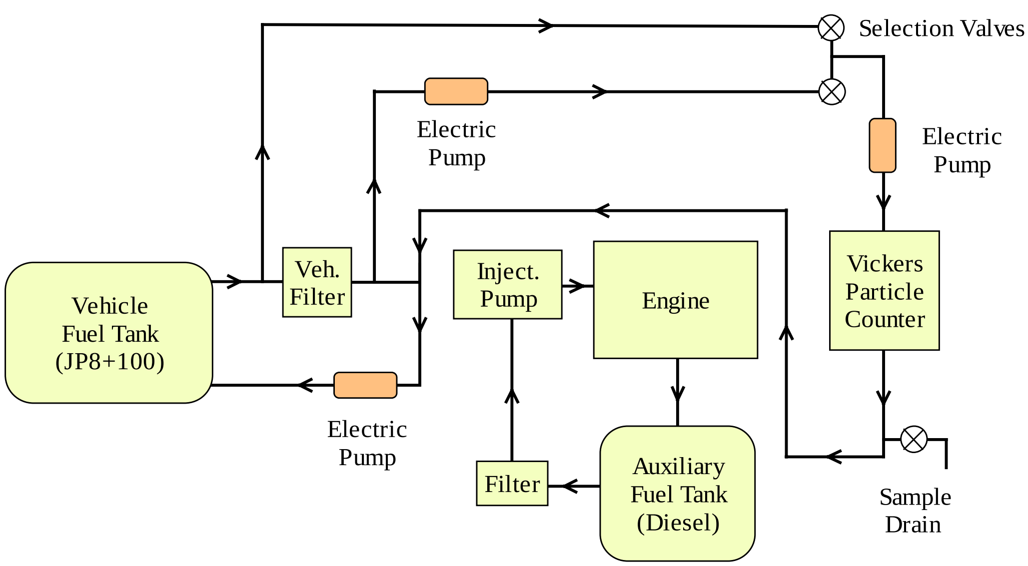


Figure 10. Vickers Particle Counter 5-ton Truck JP-8+100 Test Configuration

Soon after adding the JP-8+100, the faulty generator caused a low battery problem. Due to the fact that the truck fuel filter is a "draw through" type, i.e. it is connected to the low pressure side of the fuel injection pump, additional electric booster pumps were necessary to provide flow to the particle counter. When the battery power supplying these pumps became low, it caused a decrease in the circulation rate of the fuel. It was then necessary to interrupt the test in order to install a fresh battery for these pumps. The decreasing flow rate caused by the low battery was suspected of artificially decreasing the particle count readings because counts increased when a fresh battery was connected to the circulation pumps (Appendix C, Figures 3a and 3b). After installation of the new battery, the idle test was continued for another 30 minutes.

Following the JP-8+100 idle test, the agitated-condition testing was performed in the same manner as the diesel road test. Data was collected for slightly over an hour from both the before- and after-filter lines.

3.3.4 Discussion of Results

3.3.4.1 Idle Test

Looking at the diesel baseline data of Appendix C, Figures 1a and 1b, it can be seen that the particle concentration levels remained fairly steady throughout the tests. The calculated filtration efficiencies for the 2μ to 14μ particles are quite low compared to those of the HMMWVs, perhaps owing to the different type of filter used on this vehicle. There is also a noticeable lack of larger particles, which were expected with the fuel tank's rusty condition.

The data from the JP-8+100 idle test show only a moderate increase in particle counts upon introduction of the JP-8+100 to the diesel tank. Due to the encountered battery difficulties, the results of this procedure are probably not reliable, and it would be difficult to base any specific conclusions on this data. The data is valuable mainly for its comparison to the JP-8+100 road test results.

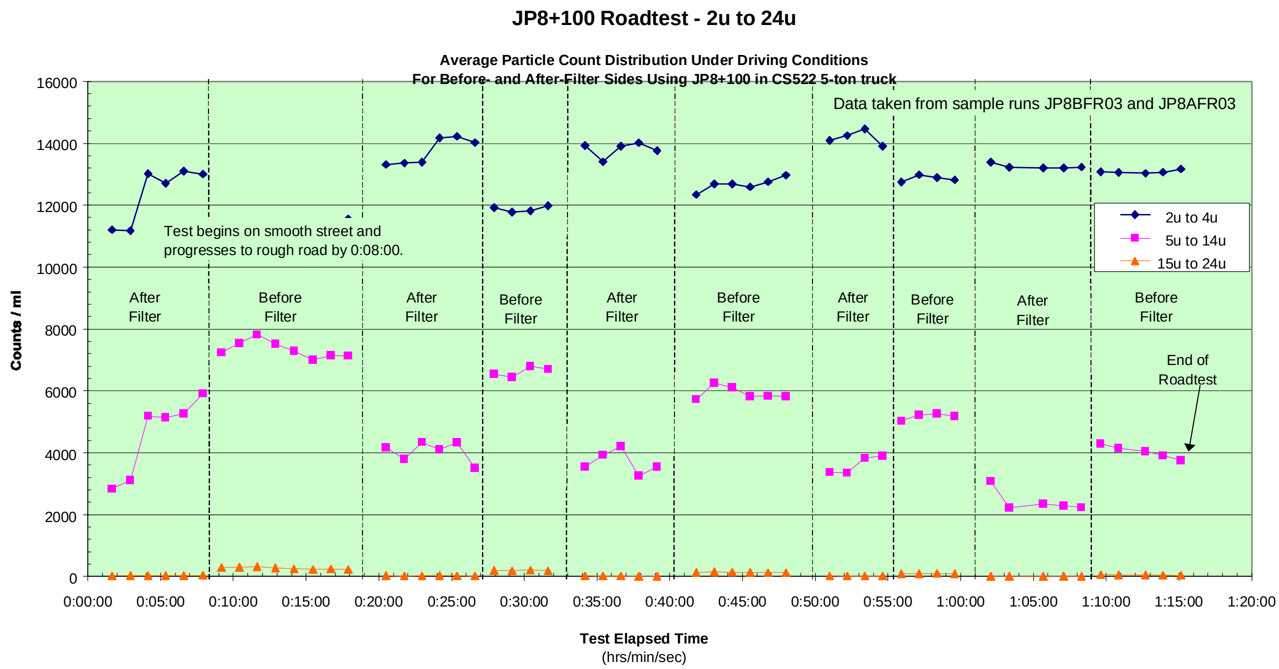
3.3.4.2 Road Test

A large increase can be seen in the concentration levels of 5µ and larger particles in the diesel road test data (Appendix C, Figures 2a-c) when compared to the diesel idle test results. The agitation caused by the vehicle motion appears to allow many particles settled at idle to become suspended in the fuel while driving. There are some occurrences of particles up to 100µ and larger, but their appearance on the after-filter side is not very substantial.

A curious phenomenon can be observed by looking at the before- and after-filter counts for the 2µ to 4µ range of the diesel road test. One would normally expect to see fewer particles on the after-filter side than the before-filter side in this situation, but the reverse is true for this case. For the majority of the test samples, the total counts of all particles remained at a fairly constant value of about 22000/milliliter on both sides of the filter. This means that if a decrease was seen in one size range, there must be an increase in another. Therefore, when the count of the 5µ and larger particles decreases in the after-filter sample, the count of the 2µ to 4µ range must increase. This indicates that some of the particles that were counted as 5µ or larger on the before-filter side must have broken into smaller pieces as they passed through the filter. Since this event did not occur in any of the other vehicles tested, it may be related to differences in fuel tank conditions, the different type of filter used on this vehicle, or a difference in the particulate matter itself.

When the JP-8+100 road test data of Figure 11 are compared to the diesel road test data, it can be seen that the particle counts tend to decrease as the particle size increases. This may be attributable to the lower density of the JP-8 fuel, which would allow particulate matter to settle out more quickly.

A comparison of the Figure 11 road test data to the JP-8+100 idle data also reveals only slight increases in the after-filter concentration levels of all particle size ranges. Filtration efficiency remains low for small particles, but tends to increase with particle size.



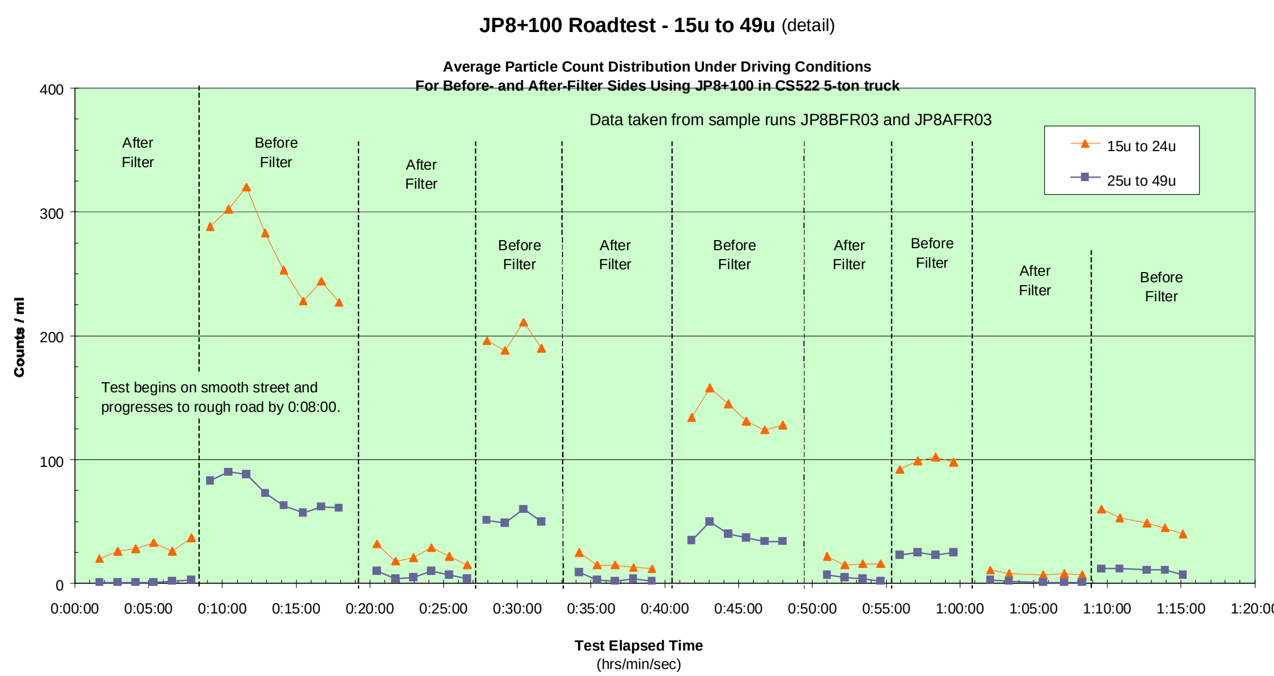


Figure 11. JP-8+100 Road Test Data

3.4 CS100 and CS200 HMMWVs

These two HMMWVs were tested using JP-8+100 in CS200 and JP-8-neat in CS100 so that the effects of fuel with and without the +100 additive could be compared. Also, using the knowledge gained in testing the previous vehicles, a slightly different approach was adopted to test these two vehicles. Particle counting duties were performed with the aid of two Met One counting units. These particle counters are not self-contained like the Vickers unit, and require the use of a personal computer for operation. Therefore, both of these vehicles were tested only under stationary, idle conditions. A borescope inspection of both vehicle fuel tanks revealed conditions similar to the previous HMMWVs. A fine residue could be seen along the bottom of the tank, with a varnish-like coating covering the sidewalls. The experimental procedure followed the same format described in the basic testing procedure outline, with the following additional details.

3.4.1 Testing Procedure

A new strategy was developed to rectify the problem of non-overlapping data time frames that occurred with the testing procedure used on the CS500 HMMWV. This new approach would help facilitate a better comparison between the results of each vehicle and each test fuel.

In order to collect data that would show the particulate concentrations of the before-filter side and the after-filter side simultaneously, one of the Met One particle-counting units was connected to each sampling line for the baseline diesel test configuration (Figure 12), and the JP-8 test configuration (Figure 13). Unlike the Vickers portable counter, the Met One system sampled continuously and automatically, allowing more evenly spaced data points. The sampling time and hold time (period between samples) are determined by the operator in order to suit the application. For this case, a sampling time and hold time of 55 and 5 seconds, respectively, were used. In this manner, samples would be taken every minute. The total length of time taken to run each test was three hours. From the experience of earlier testing, this length of time was deemed sufficient for the fuel to be fully circulated and the particle concentration levels to stabilize.

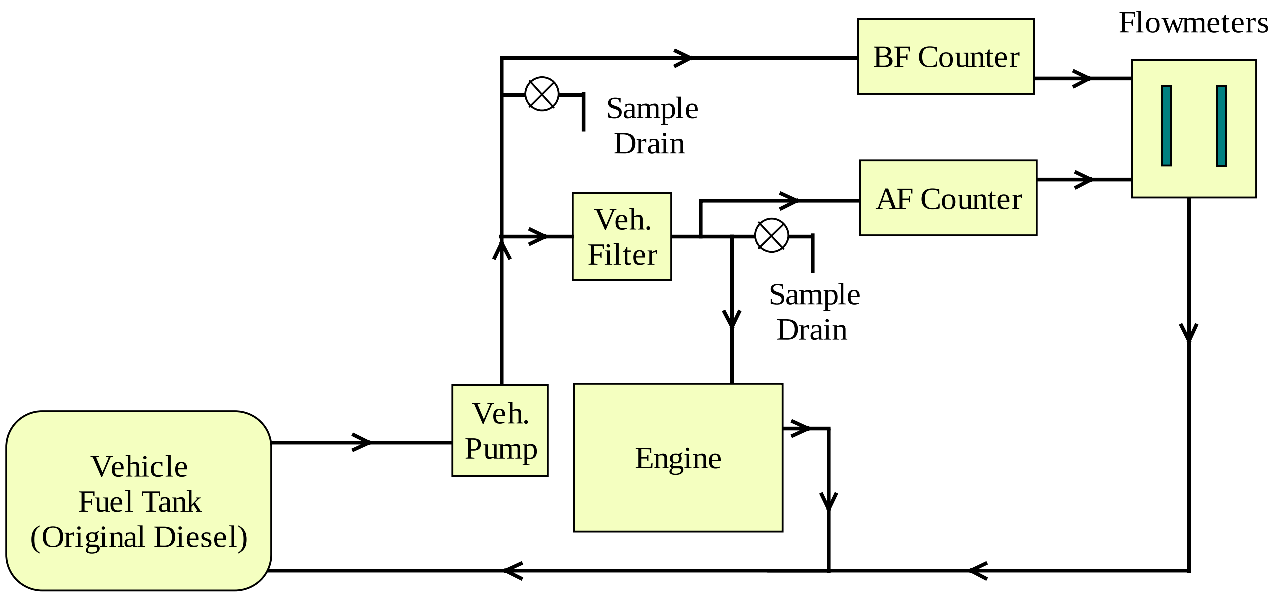


Figure 12. Met One Particle Counters HMMWV Original Diesel Test Configuration

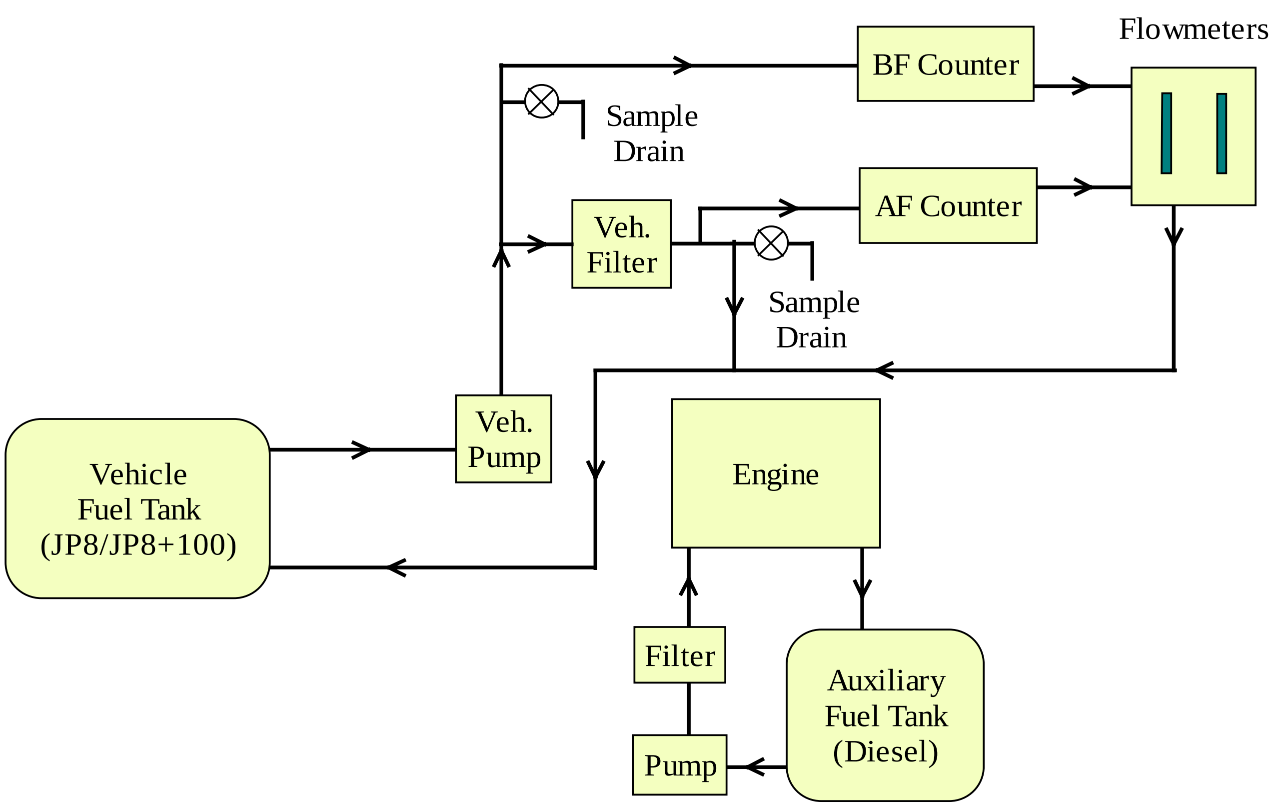


Figure 13. Met One Particle Counters HMMWV JP-8/JP-8+100 Test Configuration

In each test case, with JP-8 or diesel fuel in the tank, the vehicle was allowed to sit overnight before beginning the actual test. This allowed sufficient opportunity for any fuel system contaminants to settle, thereby equalizing the startup conditions of each test. Another important fact related to the changeover to JP-8 in these vehicles is that the fuel was not circulated through the fuel system before the test started on the following day. The JP-8 fuel was added to the vehicle tank only after completing conversion of the engine to run on the auxiliary fuel supply and performing the necessary test runs. Using this procedure, any debris flushed out of the fuel system by the JP-8 would be recorded with the particle counters upon startup of the vehicle.

3.4.2 Discussion of Results

The particle count data acquired from testing these two vehicles are presented in graph form in Appendices D and E. Also present are graphs that illustrate the *difference* in the particulate concentration levels when comparing the effects of the JP-8-neat or JP-8+100 to the vehicle's original diesel fuel. These graphs sometimes show a large spike for the first or second runs, which is probably caused by air bubbles in the lines as the JP-8-neat or JP-8+100 begin to circulate. Discussion of the test results is based upon these difference plots since they provide a convenient means of comparison. Filtration efficiency plots are also presented for each test case in Appendices D and E.

3.4.2.1 CS200 HMMWV; JP-8+100 vs. Diesel

Looking at the CS200 JP-8+100 versus diesel difference plots (Appendix D, Figures 3A-3O), it is seen that soon after the vehicle is started and the JP-8 begins to circulate, there is a large surge in the before-filter particle concentration difference levels. The peaks of these difference levels descend in magnitude as the size of the indicated particles increases, i.e. the 3μ to 4μ range has the largest difference and the 20μ and larger particles have the smallest difference. For all of the particle size ranges, except 3μ to 4μ, these surge peaks occur within the first 10 to 15 minutes after startup. Reflecting the state of the fuel in the vehicle's tank and supply line, these large surges are likely due to the cleansing action of the JP-8+100 as it carries along deposits and sediments left by the diesel fuel. After the initial surge, the particulate-difference counts gradually decrease, eventually nearing or dropping below zero, which indicates that the JP-8+100 contains the same amount or fewer particles in suspension than the diesel fuel at the same reference point. In general, the rate at which the count difference decreases varies according to particle size. This appears to be due to the larger, heavier particles falling out of suspension more quickly. It is also likely that the larger particles are being trapped in the filter as the fuel circulates, thereby decreasing the available population. The exception to this behavior is again in the 3μ to 4μ range. Even after more than two hours of running time, large surges continue to occur in the before-filter counts, indicating that these small particles are very slow to settle. It is also possible that new debris is being picked up by the circulating fuel, continuously adding to the in-tank population.

The after-filter difference data also show large surges in particle concentration levels with the JP-8+100 upon initial start-up of the engine. These surges also follow the trend of the smallest particles having the highest peak difference. However, with the exception of the 20μ and larger size range, the after-filter surges reach higher peak values than those of the unfiltered side. This increase in particle counts must be due to accumulated debris being washed off the fuel filter by the JP-8+100. While this "shedding" phenomenon also occurs when using diesel fuel, the JP-8 magnifies the effect with its excellent cleaning ability. As with the before-filter fuel flow, this surge of particles is fairly short-lived, and the counts begin to decrease within 10 to 15 minutes after start-up. Once the initial circulation period is passed, the JP-8+100 to diesel count-difference quickly drops. And although an elevated level of particles is still indicated by the before-filter readings, the filter appears to be effective in stopping them. A few small surges occur after this initial settling period, but after one hour, the particle count difference between the JP-8+100 and diesel tests settles to near zero for all ranges.

The graphs of Figures 14 and 15 show a summary of the average before- and after-filter particle concentration difference levels for 5-minute increments of the JP-8+100 versus diesel test. The illustrated time intervals begin with the first major surge of particles recorded for each size range following engine startup, and continue to 40 minutes past this initial surge. What can be seen from these graphs is that although there is a sustained increase in before-filter concentration levels, especially in the 3μ to 4μ range for this case, the after-filter levels decrease in the first 10 to 15 minutes after engine startup.

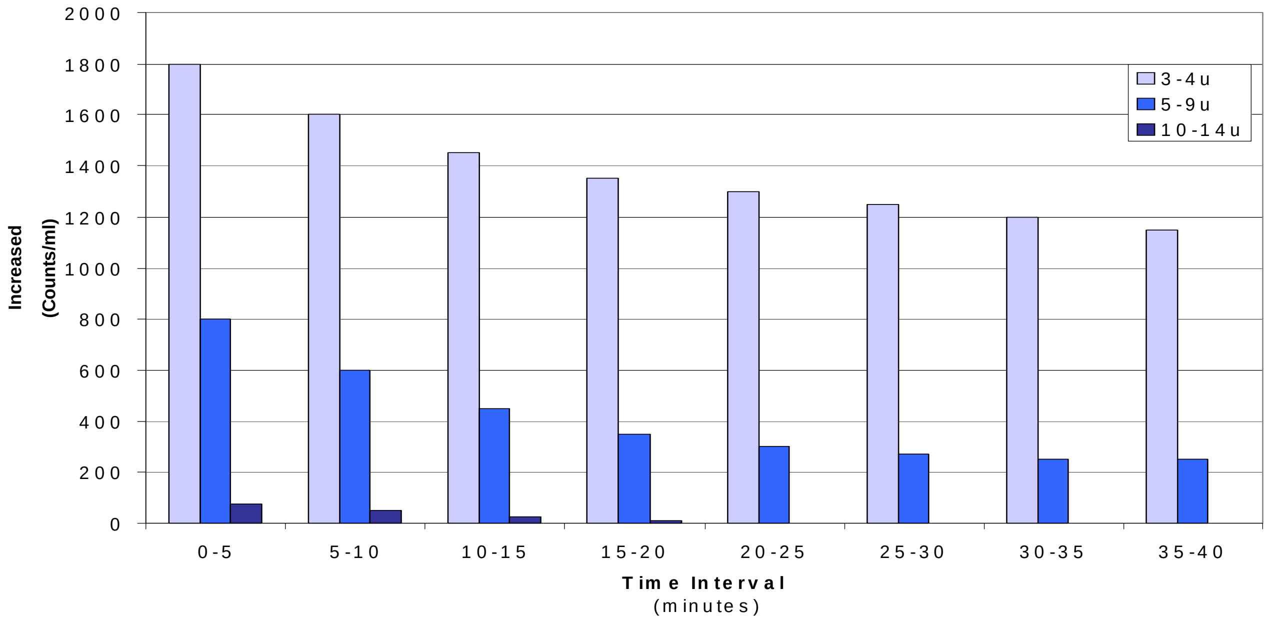


Figure 14. Average Particle Concentration Increase by Test Time Interval JP-8+100 vs Diesel, Before-Filter, CS200 HMMWV

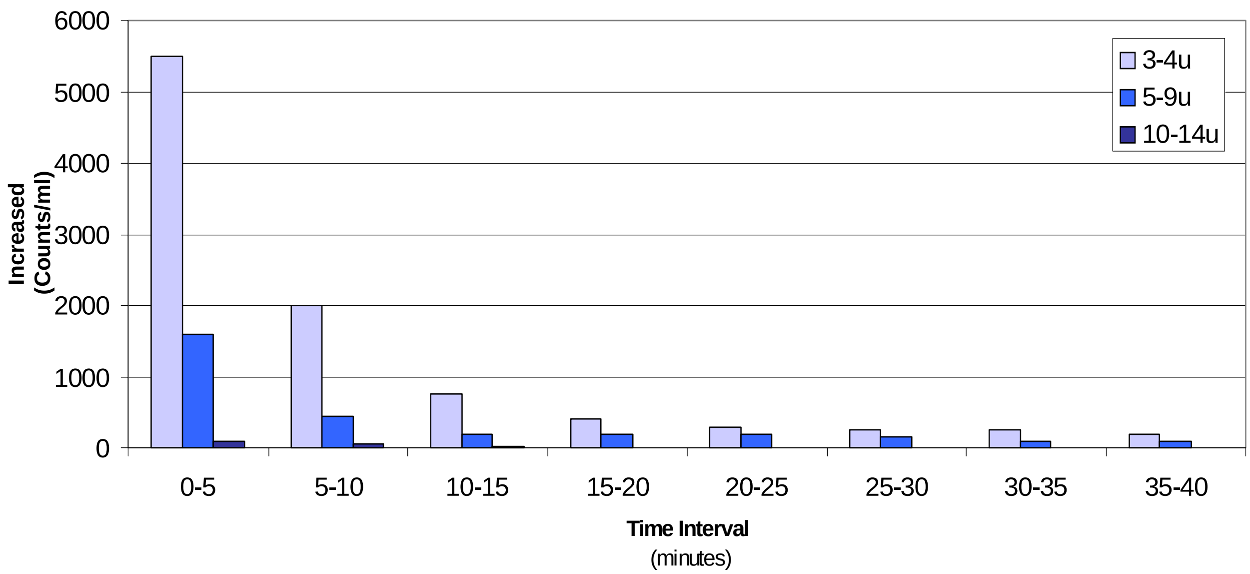


Figure 15. Average Particle Concentration Increase by Test Time Interval JP-8+100 vs Diesel, After-Filter, CS200 HMMWV

3.4.2.2 CS100 HMMWV; JP-8-neat vs. Diesel

It should be noted that the concentration-level differences of this vehicle were significantly larger than the CS200 HMMWV data. This is due to the higher level of contamination in the CS100's fuel system, as indicated by the elevated particle counts recorded for the original diesel fuel. Since there are such high concentration levels for the CS100 compared to the CS200, a change in counts that appears large on the CS200 data may be minor on the CS100 data plot. This makes the JP-8-neat graphs appear less erratic than the JP-8+100 test, but at the same scale, they would appear similar. This must be taken into consideration when comparing the data from these two tests, which limits any comparisons to general trends that can be applied to both sets of data.

As in the JP-8+100 results, as the vehicle is started and the JP-8-neat begins to circulate, a large surge occurs in the before-filter particle concentration difference levels. Likewise, the same basic pattern is followed, with surges peaking within the first 10 to 15 minutes after startup and gradually dropping to near zero over time. The largest peak difference occurs with the 5μ to 9μ particles, followed by the 3μ to 4μ, 10μ to 14μ, 15μ to 19μ, and finally, the 20μ and larger group (Appendix E, Figures 3A-3E).

The JP-8-neat after-filter data likewise show large surges in particle concentration levels upon initial start-up of the engine. As with the JP-8+100 test, except the 3μ to 4μ size range, the after-filter surges reach higher peak values than the unfiltered side, again due to debris coming off the filter element. As also seen with the JP-8+100 results, the after-filter count difference between the JP-8-neat and diesel fuel eventually settles to near zero by the end of the 3-hour test run (Appendix E, Figures 3F-3J).

Figures 16 and 17 illustrate the particle concentration difference levels for 5-minute increments of the JP-8-neat versus diesel test. Similar to the results of the JP-8+100 test is the fact that the before-filter particle count difference remains elevated for a substantial length of time, while the after-filter particle count difference drops relatively rapidly. However, it can be seen in this case that the concentrations are much higher for all particle sizes, both before and after the filter. It should also be noted for this case that the levels of the more abrasive 5μ to 9μ particles are extremely high, therefore posing a threat of injection-system component damage upon first introduction of the JP-8-neat fuel.

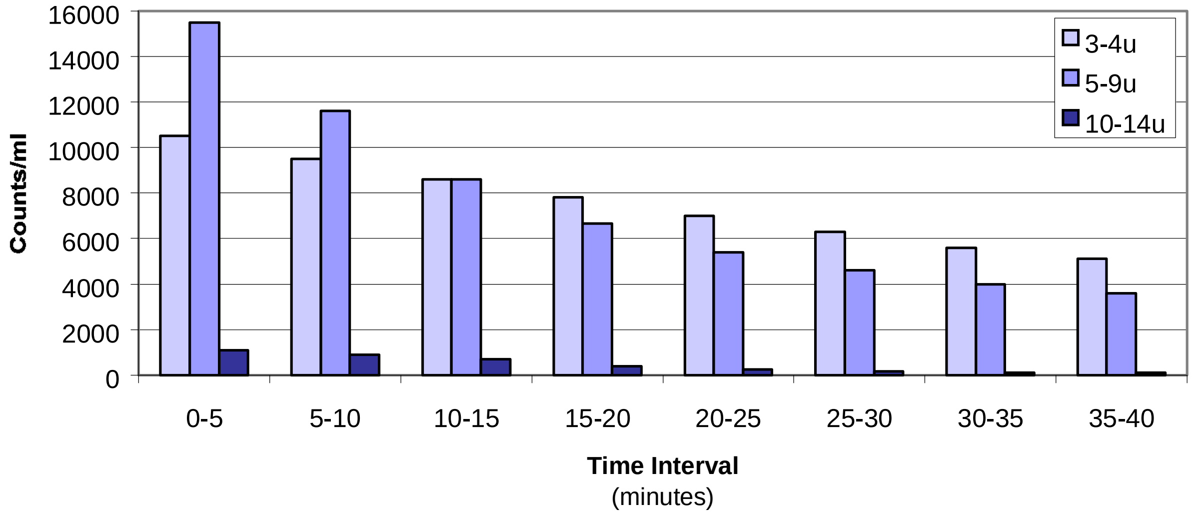


Figure 16. Average Particle Concentration Increase by Test Time Interval JP-8-neat vs. Diesel, Before -Filter, CS100 HMMWV

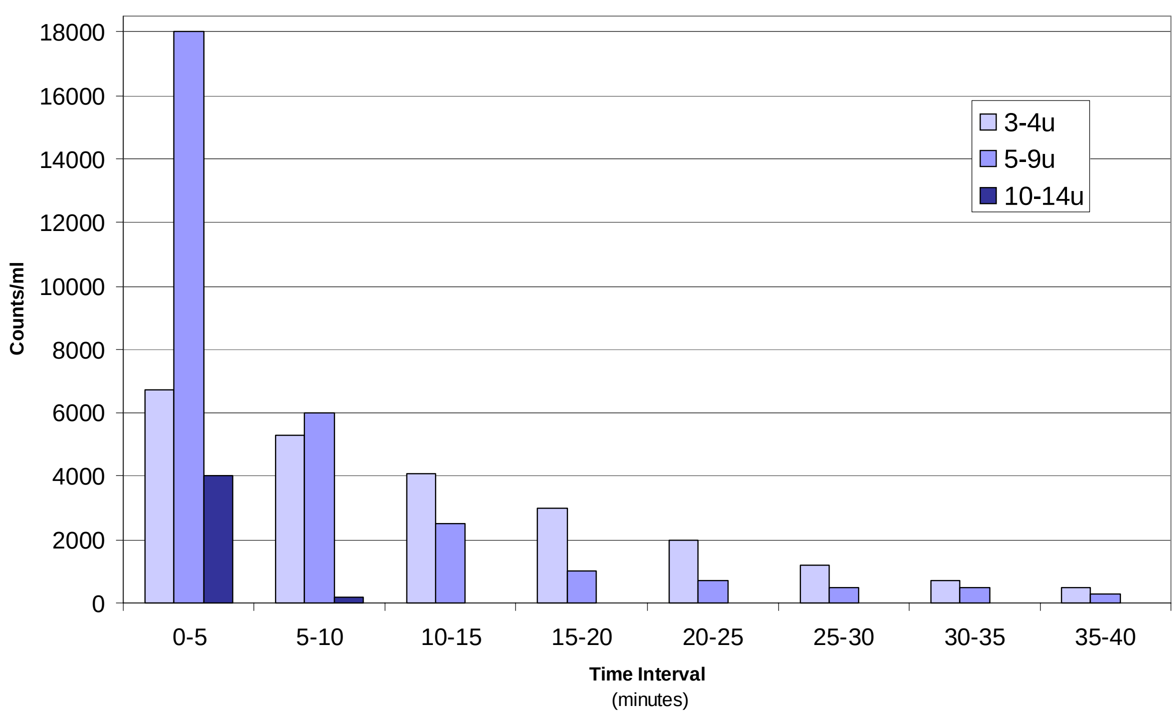


Figure 17. Average Particle Concentration Increase by Test Time Interval JP-8-neat vs. Diesel, After -Filter, CS100 HMMWV

3.4.2.3 Filtration Efficiency

Appendix E (Figures 1f and 2g) and Appendix D (Figures 1f and 2i) show graphs of filtration efficiency for vehicles CS100 and CS200. Efficiency levels with the diesel fuel were very similar for both vehicles in the 3μ to 19μ size ranges, with steady-state values ranging from approximately 70 to 90 percent. The filtration efficiency of the 20μ and larger particles is erratic due to the low number of counts in this range and is therefore not suitable for comparison. The filtration efficiency graphs clearly illustrate the effect of the previously discussed particle shedding that occurs during initial vehicle startup. Due to the very large quantity of debris being flushed from the engine side of the filter, the initial filtration efficiencies are of negative magnitude. The graphs demonstrate that the amount of time required for transition to a positive filtration efficiency, under steady-flow conditions, is basically a function of particle size. It can be seen that efficiency for the smaller particles tends to increase the most rapidly, indicating that they are more easily flushed off the filter element. Generally, after about an hour of circulation at idle speed, the diesel fuel filtration efficiencies for all particle sizes approach positive values.

A comparison of the steady-state JP-8+100 filtration efficiency (CS200) to diesel efficiency shows a slight improvement for particles in the 3μ to 19μ range. However, the length of time required to reach this steady-state condition is longer since the particle-shedding process is intensified by the JP-8+100. The steady-state filtration efficiency with the JP-8-neat (CS100) is seen to decrease approximately 5% for the 3μ to 9μ particles and almost 20% for the 10μ to 14μ range. Values for the 15μ and larger ranges are erratic due to low quantities of these particles.

3.4.3 Conclusions

As mentioned previously, the limits of these tests do not allow a true comparison to be made between the effects of JP-8-neat and JP-8+100. In fact, the data presented show more similarities than noticeable differences. The results of both tests demonstrate that JP-8-neat and JP-8+100 have a “cleansing” effect, which causes a temporary increase in the concentration levels of fuel-borne contaminants. The magnitude of this increase appears to be dependent upon the condition of the original diesel fuel and the fuel system components prior to addition of the JP-8 fuels, with the largest increases occurring in the 3μ to 15μ size ranges. With the JP-8 fuel circulating at engine idle speed, the after-filter-side concentration of fuel-borne particles normally returns to that of the original diesel fuel within 1 hour or less.

The results obtained with these two HMMWVs demonstrate that although the initial use of JP-8 and JP-8+100 fuels in vehicles previously operated on diesel fuel causes a large increase in fuel-borne particulates, the particle-stopping ability of the fuel filter is not necessarily diminished by their use. After-filter data for both fuels show that once the particle-shedding event ceases, the effectiveness of the filter is unchanged at steady-state idle conditions. The main risk of damage to fuel-injection system components appears to be from the initial surge of contaminants released into the engine-bound fuel stream by the filter-cleansing action of the JP-8 fuels.

3.5 Results of Laboratory Particulate and Water Analysis

3.5.1 Particulates

ASTM gravimetric particulate analysis D-5452 and Karl Fischer water content analysis D-6304 were performed on the fuel samples extracted from each vehicle, and the results are presented in Appendix F, Figure 1a. The only deviation from the ASTM test methods was that the fuel samples were much smaller than specified in the ASTM procedures due to the impracticality of collecting such large volumes of fuel from each vehicle. In general, a comparison of the particulate mass measured in each sample to the particle counts recorded when that sample was drawn reveals that an increase or decrease in measured particulate mass per liter of fuel corresponds to an increase or decrease in the counts per milliliter of particles in the 5μ and larger size ranges. A good example supporting this observation is the data for the 5-ton truck, vehicle CS522, which had prominent oxidation on the fuel tank surfaces. The diesel road test particle count data for this truck revealed the presence of particles ranging to over 100μ in size, much larger than those found in any of the other tested vehicles. It therefore makes sense that the mass quantity of particulates measured in this fuel were higher than that of any other vehicle.

3.5.2 Water Filtration Efficiency

Using the results of the Karl Fischer water content analysis presented in Appendix F, the water filtration efficiency of each vehicle and fuel combination has been graphed and is presented in Figure 18. For cases that exhibit a negative value, the efficiency should be considered to be zero since the filter/separator cannot produce water. These anomalous values may be the result of a problem with the collected samples, or may be a reflection of error incurred due to the small size of the fuel samples utilized for the Karl Fischer test.

Figure 18 illustrates that the results vary considerably for each vehicle, with no apparent trend established between the five test cases. The concern when using JP-8+100, where fuel-borne water may be present, is that it will diminish the ability of the filter/separator to effectively remove the water. However, only two of the test vehicles, CS300 and CS522, exhibited a diminished water-removal capability when compared to the results for diesel fuel. Two of the HMMWVs, CS500, and CS200 actually showed an *increase* in efficiency with the use of JP-8+100. The plots for the vehicle that used JP-8-neat, HMMWV CS100, show negative efficiencies for both cases and must be considered invalid.

The results of this water content and filtration efficiency analysis should be considered inconclusive. More useful results could be obtained if a controlled experiment were conducted using fuels containing known amounts of water in each vehicle. This would provide a more sound basis for determining the effects of JP-8+100 on the water-separation ability of the vehicle fuel filter.

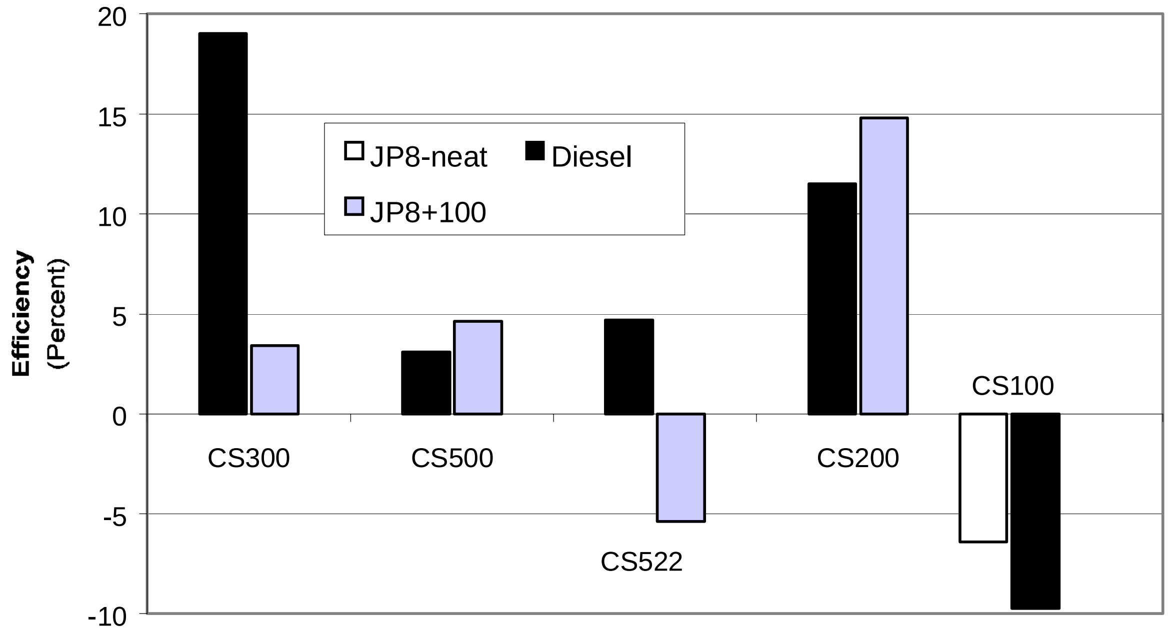


Figure 18. Water Filtration Efficiency Using JP-8+100/JP-8-net vs. Diesel

4.0 SUMMARY

The results of vehicle testing performed in this experiment demonstrate that JP-8+100 causes a temporary increase in the concentration level of fuel-borne contaminants when introduced to previously diesel-only fuel systems. The magnitude of this increase appears to be dependent upon the condition of the vehicle's original diesel fuel and fuel-system components prior to addition of the JP-8+100.

The test data presented in this report show that the largest increases in particle counts occurred in the 2µ to 15µ size range for most vehicles upon introduction of JP-8+100. It was also observed that after-filter particle counts reached higher levels than before-filter counts due to the apparent washing of accumulated debris from the filter element by the JP-8+100.

With JP-8+100 circulating at engine idle speed, the after-filter particle concentration levels normally return to that of the original diesel fuel within approximately one hour or less after engine startup, while the in-tank particle concentrations continue to be elevated for a longer period of time. At faster fuel-circulation rates (as when driving a vehicle), the time required to reduce these elevated particle counts appears to shorten.

The use of JP-8+100 in the tested vehicles appeared to have no detrimental effect on the filter's ability to remove particulate matter from the fuel stream, although calculated efficiency is initially reduced due to the shedding of particles from the downstream side of the filter. This was equally true for the stationary and road test cases. The data also indicate that larger particles tend to settle out of the JP-8+100 more quickly than in diesel, probably due to the slightly lower density and viscosity of JP-8+100.

The results of this experiment do not appear to support the hypothesis that JP-8+100 allows a higher percentage of particles to pass through the fuel filtration system, either due to the theorized formation of a particle "cloud" or otherwise. Any increase in after-filter particle concentration levels seems to be more attributable to the shedding of debris from the filter element than from passage through the filter. This can be supported by examining the JP-8+100 versus diesel difference data with regard to the fact that there are instances where the before-filter concentration is very high, but the after-filter readings are near zero for the same time frame.

In light of the aforementioned debris-shedding, the main risk of damage to fuel injection system components appears to be from the large initial surge of contaminants released into the engine-bound fuel stream by the filter-cleansing action of JP-8+100. Although this study did not examine the wear-related effects of this sudden surge in particulate levels, it may be possible that a short-lived but large increase in these contaminants could cause accelerated wear on the fuel-injection pump and injectors.

Water analysis of vehicle fuel samples was inconclusive, with results varying for each vehicle. Further testing with controlled fuel/water ratios would be necessary to determine the true effect of the +100 additive on filter/separator performance.

Testing performed with JP-8-neat produced results very similar to those observed with JP-8+100 in terms of particle concentration level changes upstream and downstream of the fuel filter. However, since it was necessary to evaluate each case using a different vehicle, fuel system conditions varied from test to test. This, combined with the fact that the JP-8+100 and JP-8-neat were obtained from different sources, prevents forming a valid comparison between the effects observed with the two fuels.

5.0 RECOMMENDATIONS

The scope of this experiment was quite general and mostly of a “first look” nature. A more thorough study would be necessary to investigate specific issues raised by the results. Some of these issues are: (a) determination of the impact of short-duration, high particle-concentration levels on component durability; (b) closer investigation of the effects of JP-8+100 on water-separation capabilities; and (c) evaluation of the long-term effects of JP-8+100 on particulate filtration ability.

Investigation of these issues would require performing experiments under controlled laboratory conditions in order to eliminate the variables encountered in the vehicle testing. The results from these laboratory experiments, along with the data compiled from vehicle testing, would then provide a more complete picture of how conversion from diesel-only operation to the use of JP-8+100 affects the life-expectancy of fuel-injection system components.

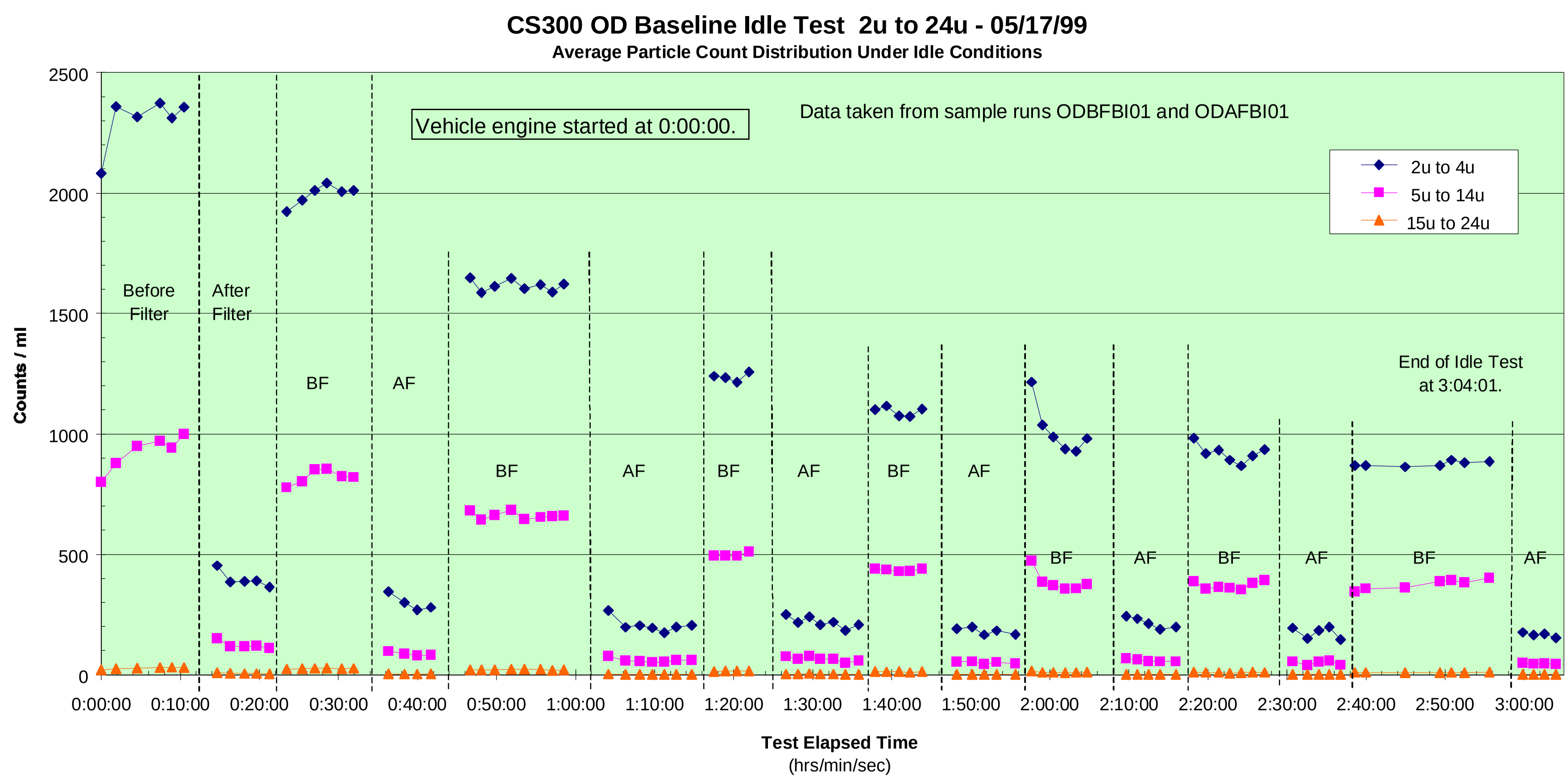
6.0 REFERENCES

1. Bessee, Gary B., Yost, Douglas M., Lacey, Paul I., et. al,, “Filtration Requirements and Evaluation Procedure for a Rotary Injection Fuel Pump,” SAE Technical Paper 972872, October 1997.

APPENDIX A

CS300 HMMWV TEST DATA

FIGURE 1A



CS300 OD Baseline Idle Test 2u to 24u - 05/17/99
Average Particle Count Distribution Under Idle Conditions
Vehicle engine started at 0:00:00.
Data taken from sample runs ODBFBI01 and ODAFBI01
2u to 4u
5u to 14u
15u to 24u
Before Filter
After Filter
BF
AF
End of Idle Test at 3:04:01.
Counts / ml
0
500
1000
1500
2000
2500
0:00:00
0:10:00
0:20:00
0:30:00
0:40:00
0:50:00
1:00:00
1:10:00
1:20:00
1:30:00
1:40:00
1:50:00
2:00:00
2:10:00
2:20:00
2:30:00
2:40:00
2:50:00
3:00:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 1B

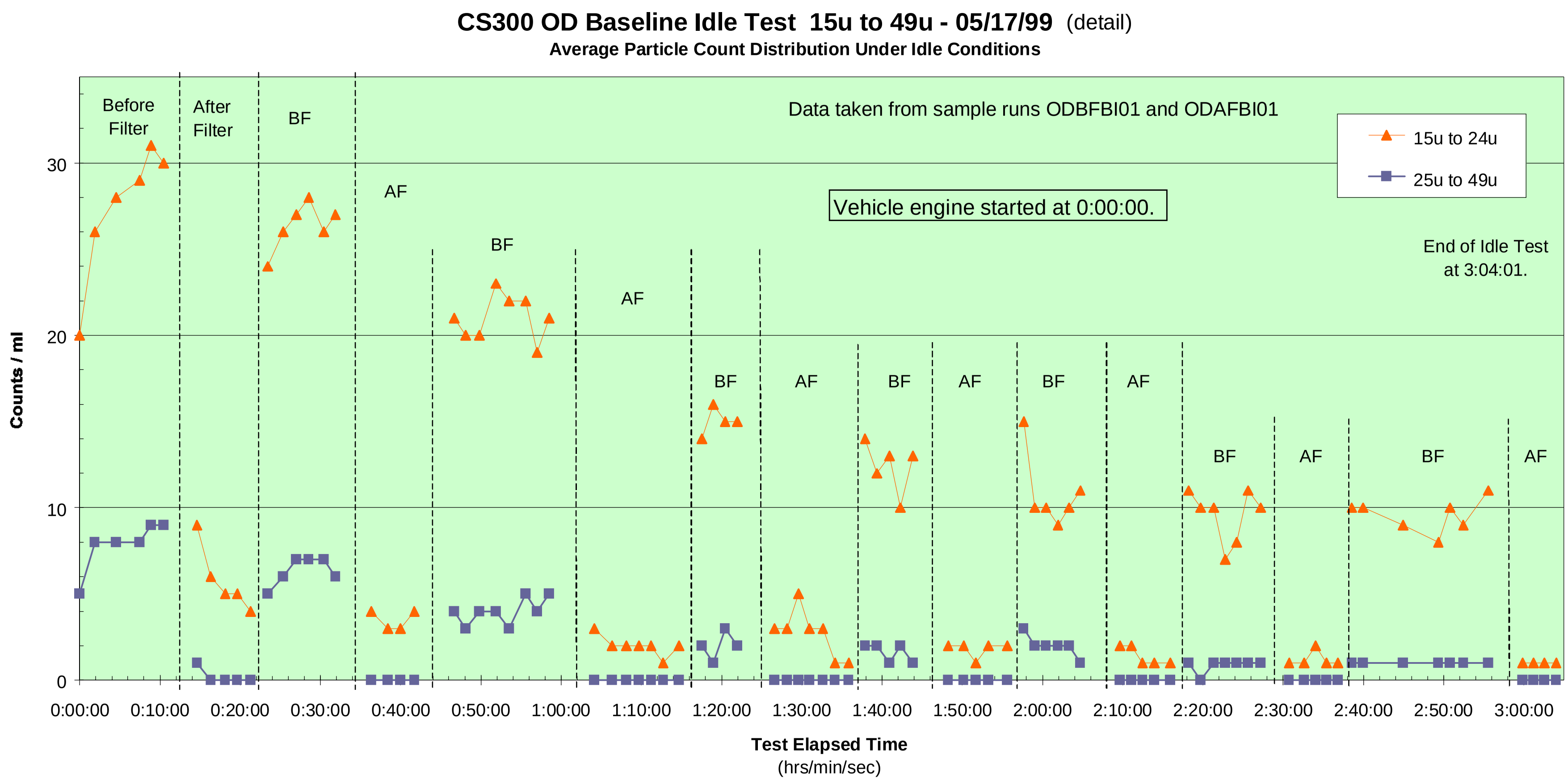

CS300 OD Baseline Idle Test 15u to 49u - 05/17/99 (detail)
Average Particle Count Distribution Under Idle Conditions
Before Filter
After Filter
BF
AF
Data taken from sample runs ODBFBI01 and ODAFBI01
Vehicle engine started at 0:00:00.
End of Idle Test at 3:04:01.
15u to 24u
25u to 49u
Counts / ml
Test Elapsed Time
(hrs/min/sec)
0
10
20
30
0:00:00
0:10:00
0:20:00
0:30:00
0:40:00
0:50:00
1:00:00
1:10:00
1:20:00
1:30:00
1:40:00
1:50:00
2:00:00
2:10:00
2:20:00
2:30:00
2:40:00
2:50:00
3:00:00

FIGURE 2A

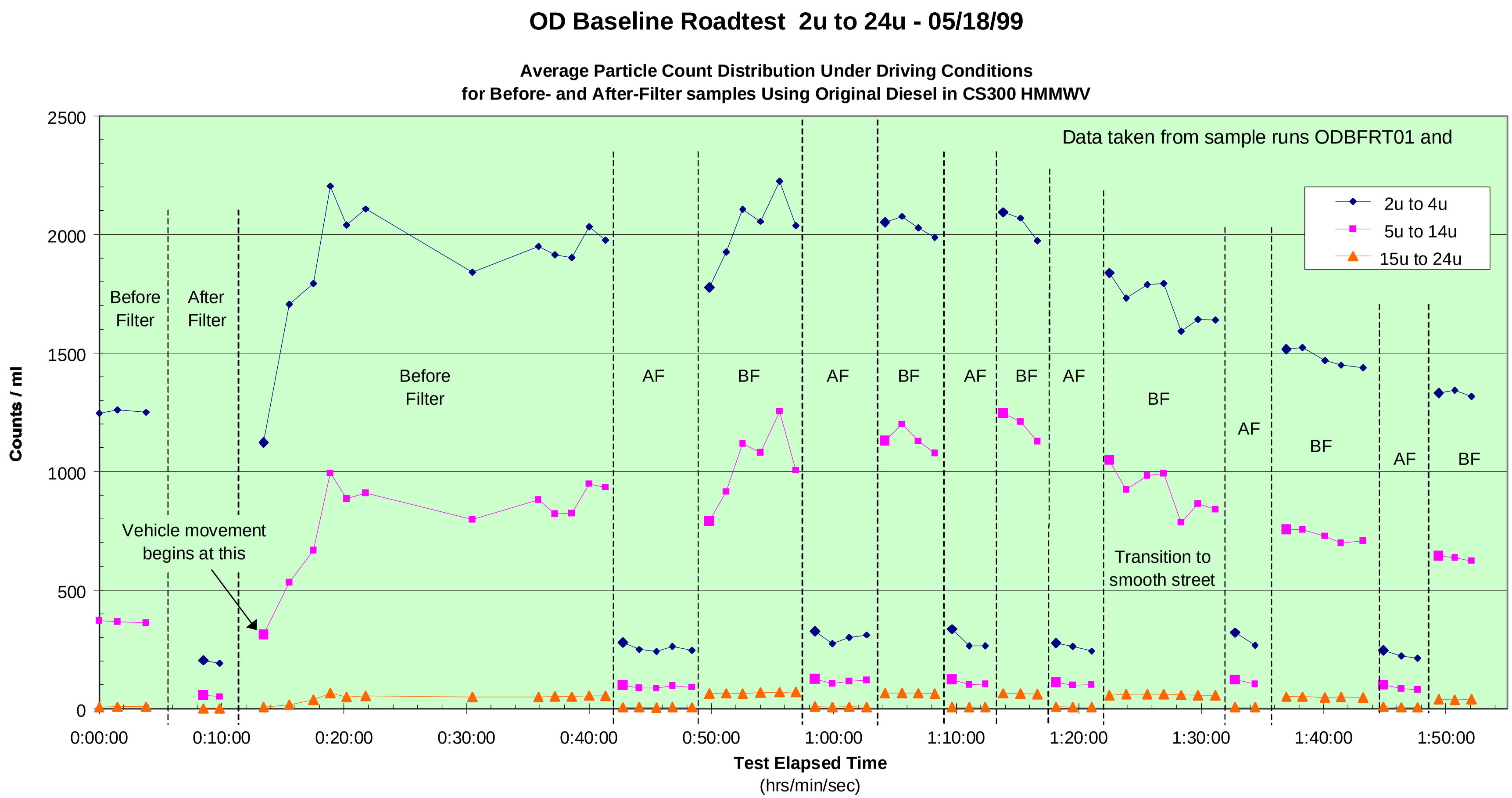
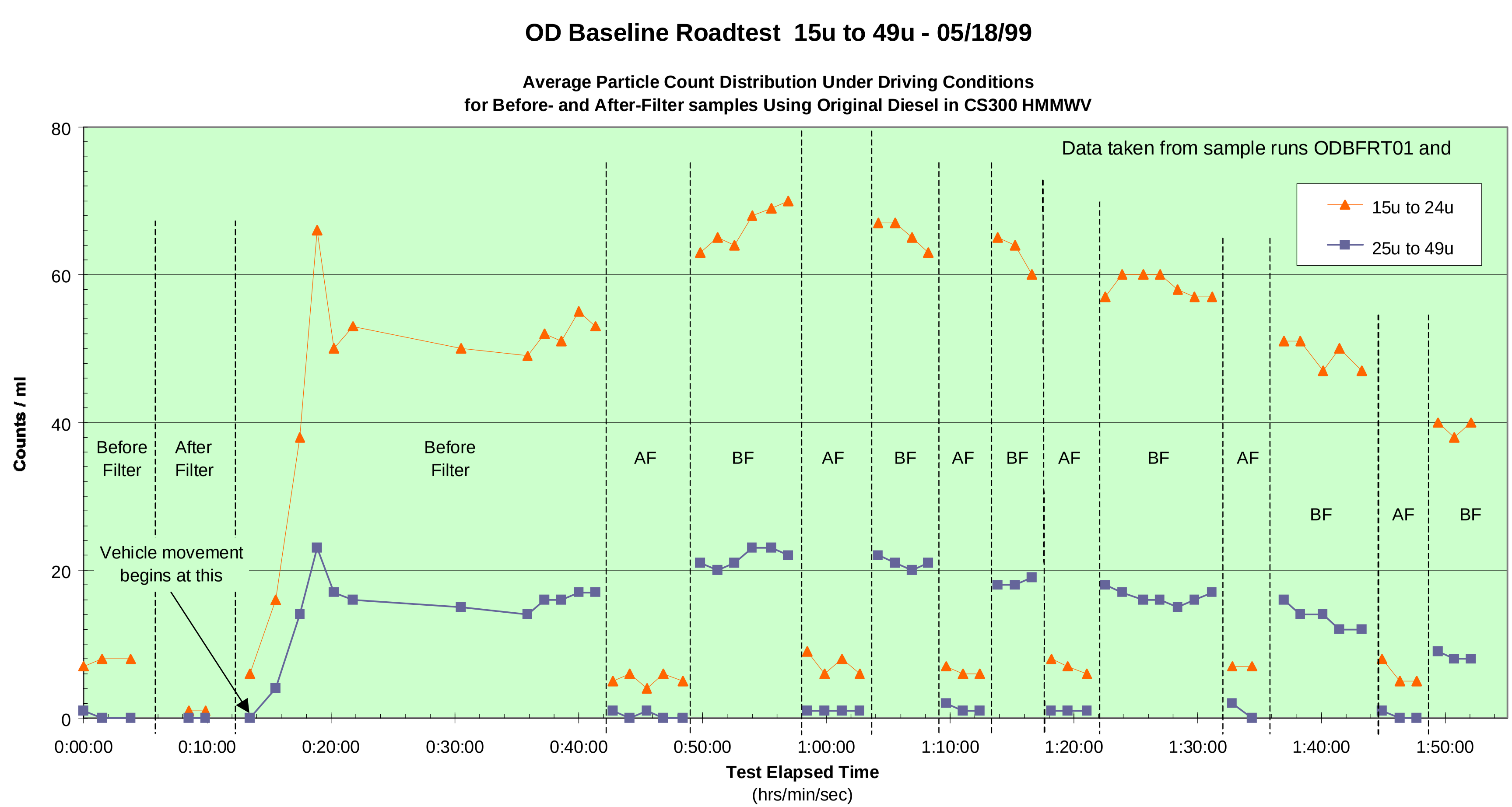

OD Baseline Roadtest 2u to 24u - 05/18/99
Average Particle Count Distribution Under Driving Conditions
for Before- and After-Filter samples Using Original Diesel in CS300 HMMWV
Data taken from sample runs ODBFRT01 and
2u to 4u
5u to 14u
15u to 24u
Counts / ml
2500
2000
1500
1000
500
0
Before Filter
After Filter
Before Filter
AF
BF
AF
BF
AF
BF
AF
BF
AF
BF
AF
BF
Vehicle movement begins at this
Transition to smooth street
0:00:00
0:10:00
0:20:00
0:30:00
0:40:00
0:50:00
1:00:00
1:10:00
1:20:00
1:30:00
1:40:00
1:50:00
Test Elapsed Time
(hrs/min/sec)

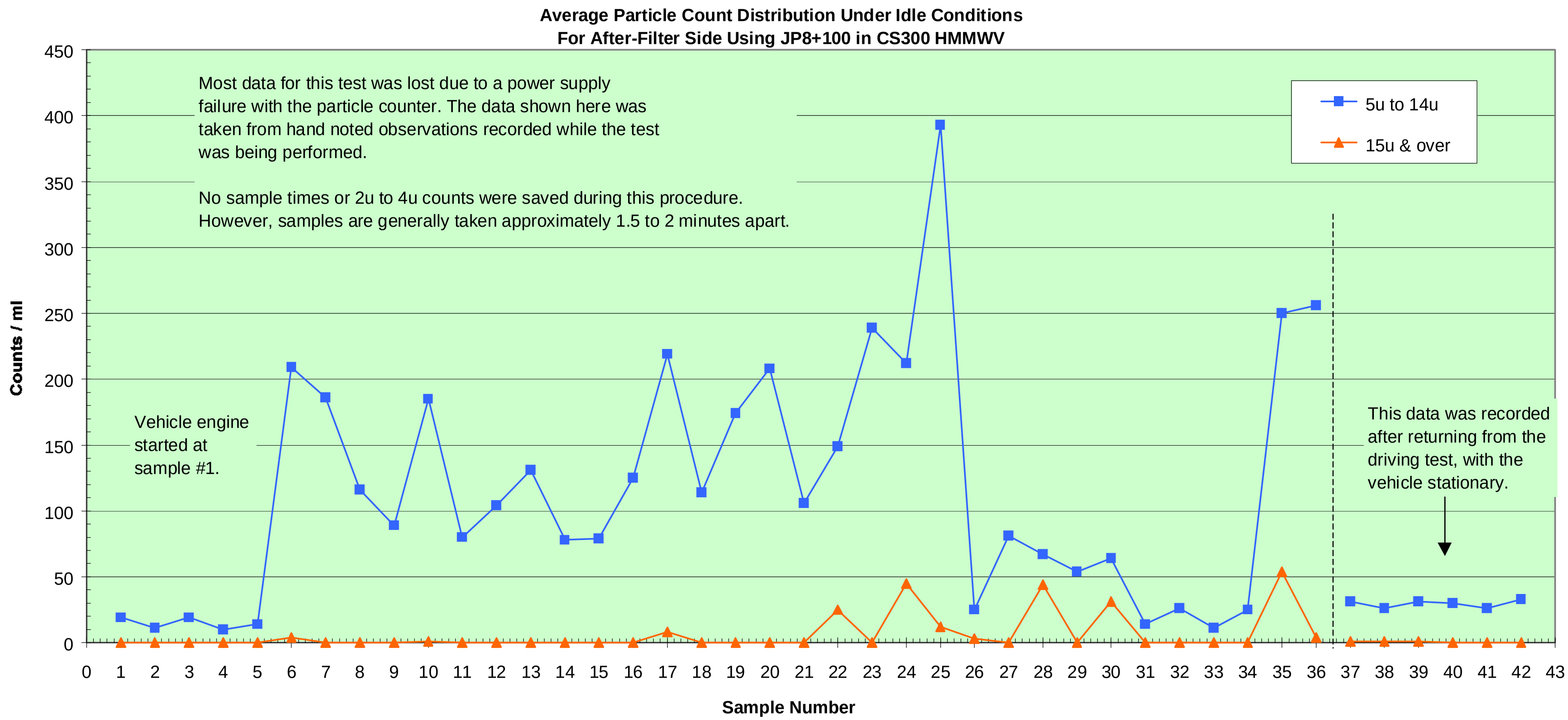
FIGURE 2B



OD Baseline Roadtest 15u to 49u - 05/18/99
Average Particle Count Distribution Under Driving Conditions
for Before- and After-Filter samples Using Original Diesel in CS300 HMMWV
Data taken from sample runs ODBFRT01 and
15u to 24u
25u to 49u
Counts / ml
0
20
40
60
80
Before Filter
After Filter
Before Filter
Vehicle movement begins at this
AF
BF
AF
BF
AF
BF
AF
BF
AF
BF
AF
BF
0:00:00
0:10:00
0:20:00
0:30:00
0:40:00
0:50:00
1:00:00
1:10:00
1:20:00
1:30:00
1:40:00
1:50:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 3

JP8+100 AF Idle Test - 5u & over - 05/18/99



APPENDIX B

CS500 HMMWV TEST DATA

FIGURE 1A

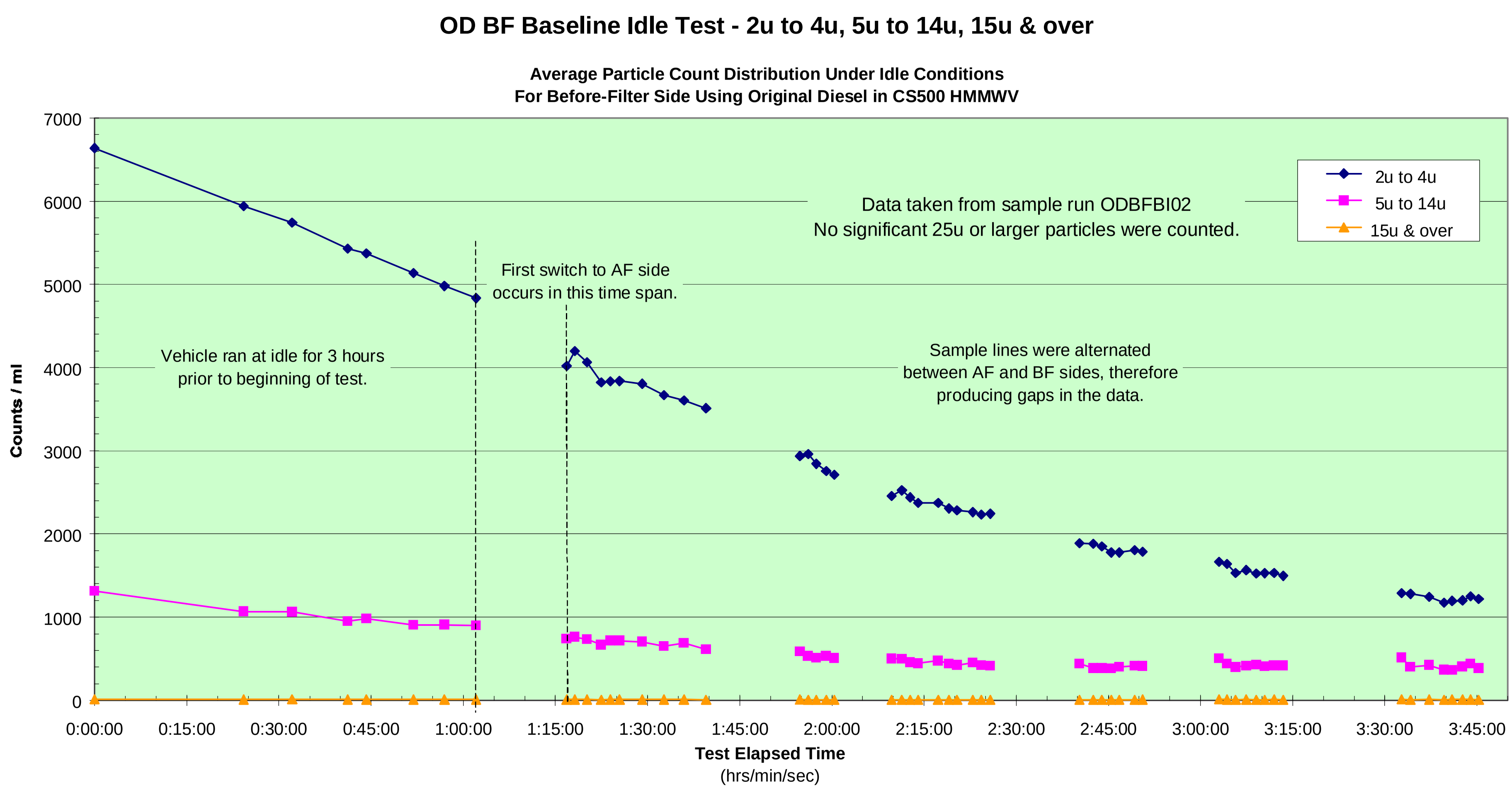

OD BF Baseline Idle Test - 2u to 4u, 5u to 14u, 15u & over
Average Particle Count Distribution Under Idle Conditions
For Before-Filter Side Using Original Diesel in CS500 HMMWV
Counts / ml
0
1000
2000
3000
4000
5000
6000
7000
0:00:00
0:15:00
0:30:00
0:45:00
1:00:00
1:15:00
1:30:00
1:45:00
2:00:00
2:15:00
2:30:00
2:45:00
3:00:00
3:15:00
3:30:00
3:45:00
Test Elapsed Time
(hrs/min/sec)
2u to 4u
5u to 14u
15u & over
Data taken from sample run ODBFBI02
No significant 25u or larger particles were counted.
First switch to AF side
occurs in this time span.
Vehicle ran at idle for 3 hours
prior to beginning of test.
Sample lines were alternated
between AF and BF sides, therefore
producing gaps in the data.

FIGURE 1B

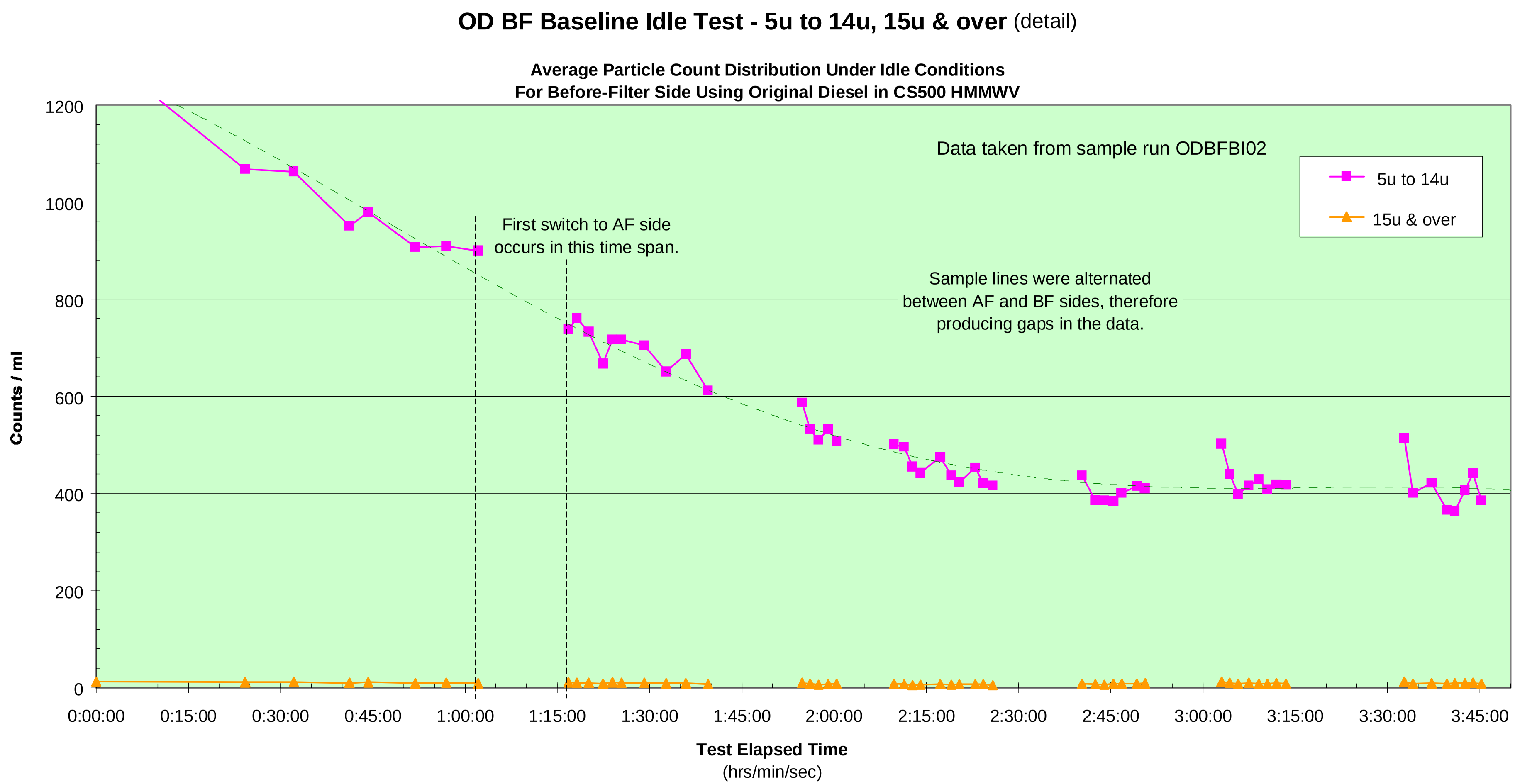

OD BF Baseline Idle Test - 5u to 14u, 15u & over (detail)
Average Particle Count Distribution Under Idle Conditions
For Before-Filter Side Using Original Diesel in CS500 HMMWV
Data taken from sample run ODBFBI02
5u to 14u
15u & over
First switch to AF side
occurs in this time span.
Sample lines were alternated
between AF and BF sides, therefore
producing gaps in the data.
Counts / ml
1200
1000
800
600
400
200
0
0:00:00
0:15:00
0:30:00
0:45:00
1:00:00
1:15:00
1:30:00
1:45:00
2:00:00
2:15:00
2:30:00
2:45:00
3:00:00
3:15:00
3:30:00
3:45:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 1C

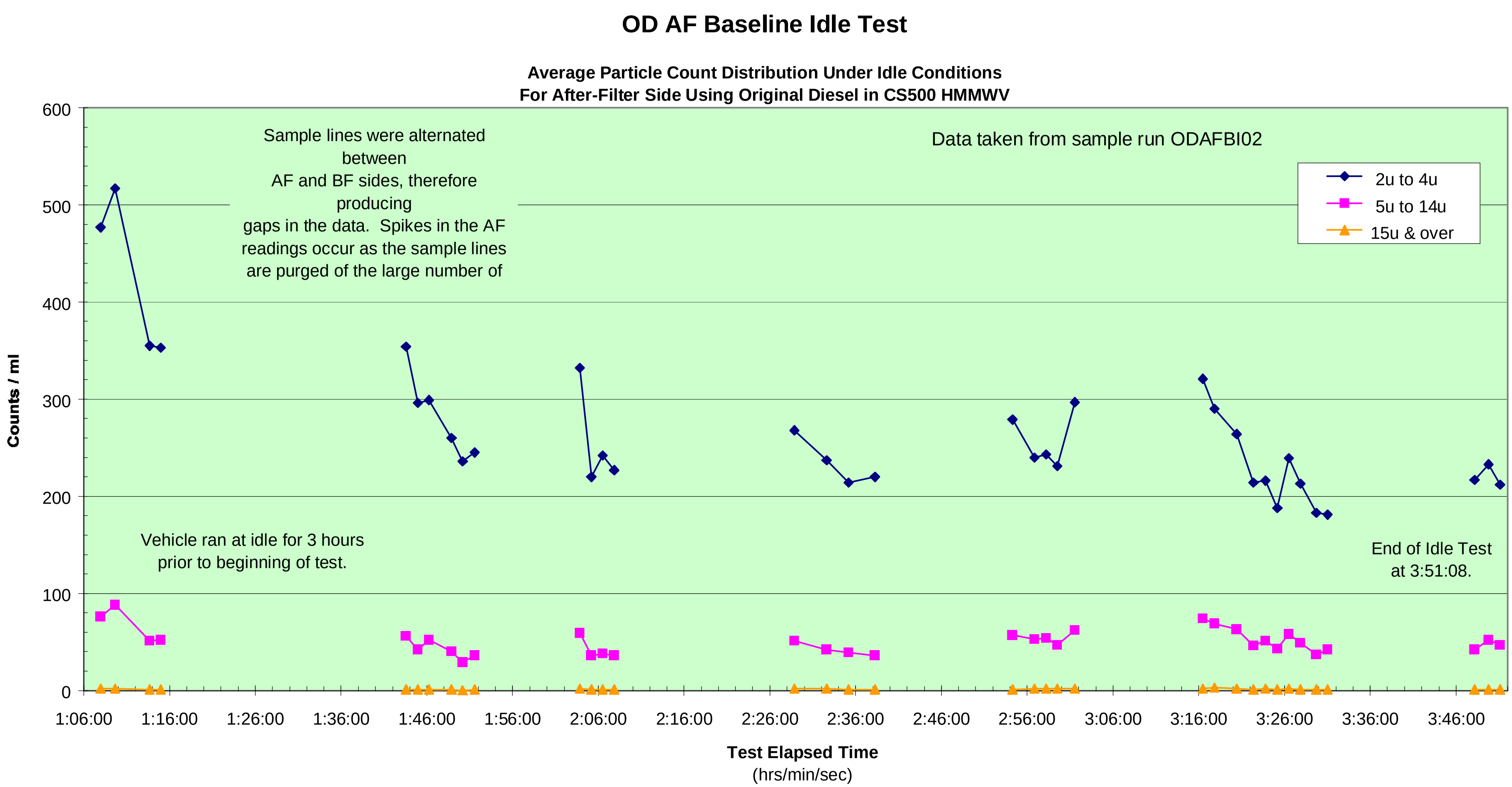

OD AF Baseline Idle Test
Average Particle Count Distribution Under Idle Conditions
For After-Filter Side Using Original Diesel in CS500 HMMWV
Counts / ml
600
500
400
300
200
100
0
Sample lines were alternated between AF and BF sides, therefore producing gaps in the data. Spikes in the AF readings occur as the sample lines are purged of the large number of
Data taken from sample run ODAFBI02
2u to 4u
5u to 14u
15u & over
Vehicle ran at idle for 3 hours prior to beginning of test.
End of Idle Test at 3:51:08.
1:06:00
1:16:00
1:26:00
1:36:00
1:46:00
1:56:00
2:06:00
2:16:00
2:26:00
2:36:00
2:46:00
2:56:00
3:06:00
3:16:00
3:26:00
3:36:00
3:46:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 2A

OD BF Baseline Roadtest - 2u to 24u

Average Particle Count Distribution Under Driving Conditions

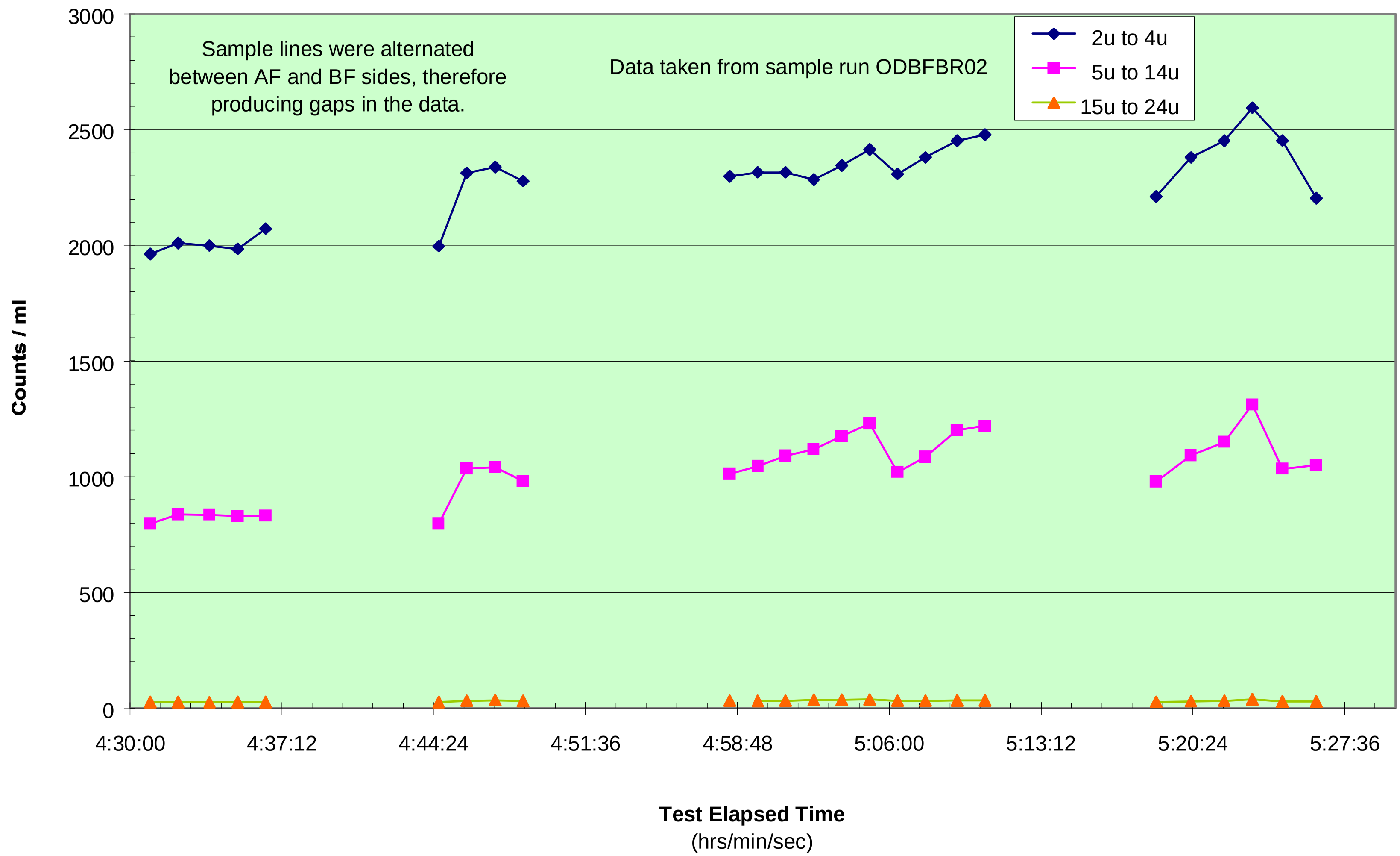


FIGURE 2B

OD BF Baseline Roadtest - 15u & over (detail)

Average Particle Count Distribution Under Driving Conditions

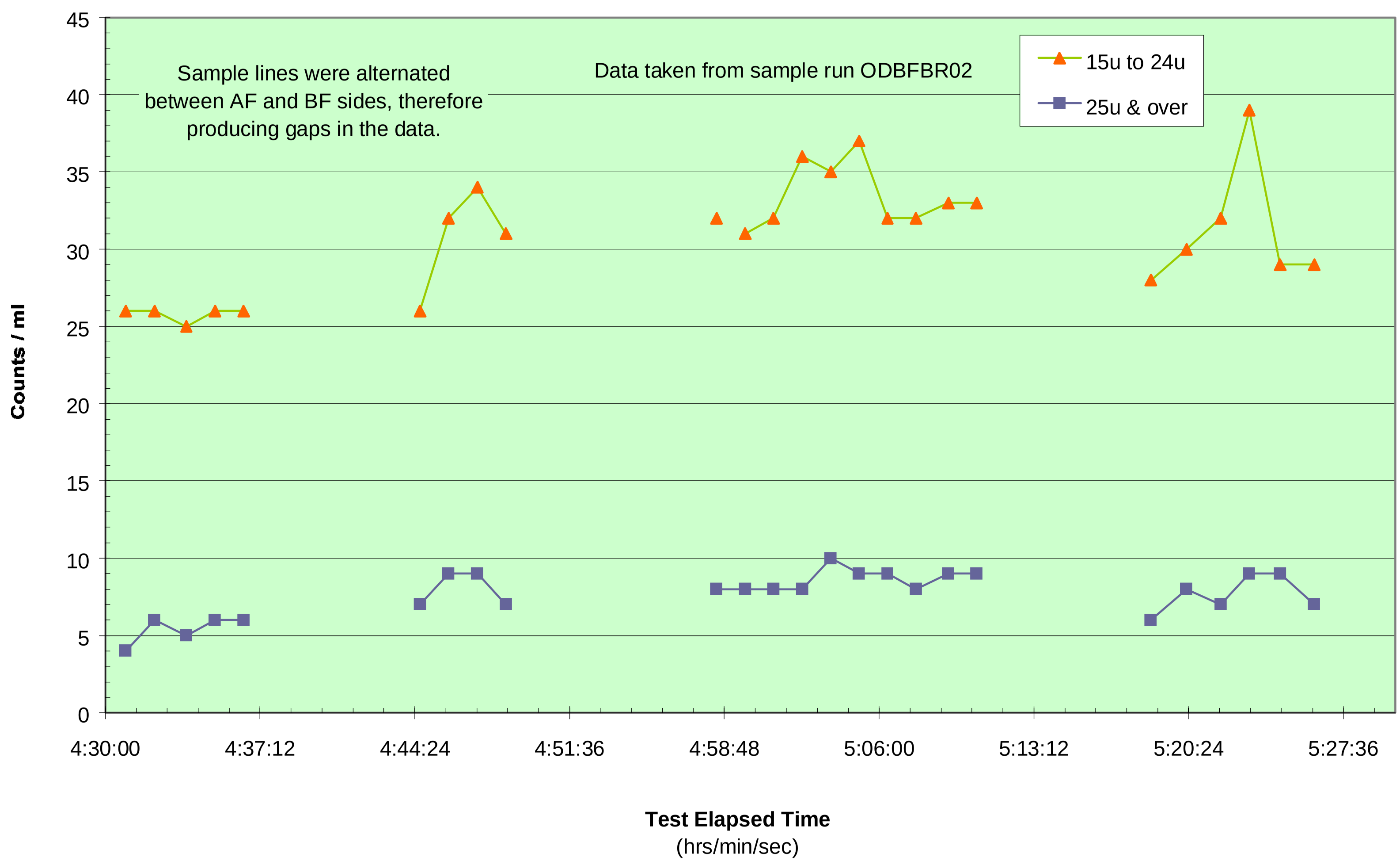


FIGURE 2C

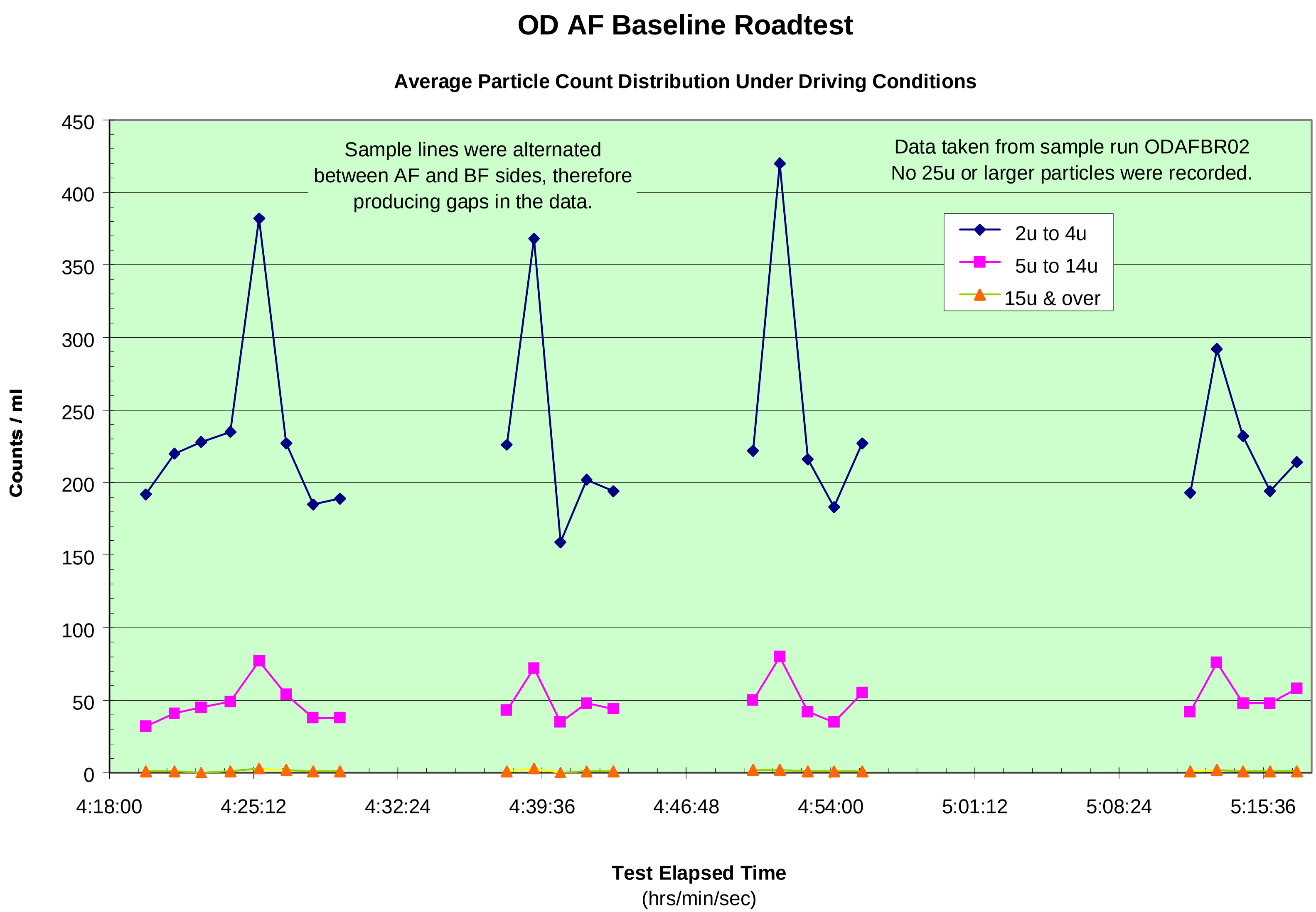

OD AF Baseline Roadtest
Average Particle Count Distribution Under Driving Conditions
Counts / ml
450
400
350
300
250
200
150
100
50
0
4:18:00
4:25:12
4:32:24
4:39:36
4:46:48
4:54:00
5:01:12
5:08:24
5:15:36
Test Elapsed Time
(hrs/min/sec)
Sample lines were alternated between AF and BF sides, therefore producing gaps in the data.
Data taken from sample run ODAFBR02
No 25u or larger particles were recorded.
2u to 4u
5u to 14u
15u & over

FIGURE 3A

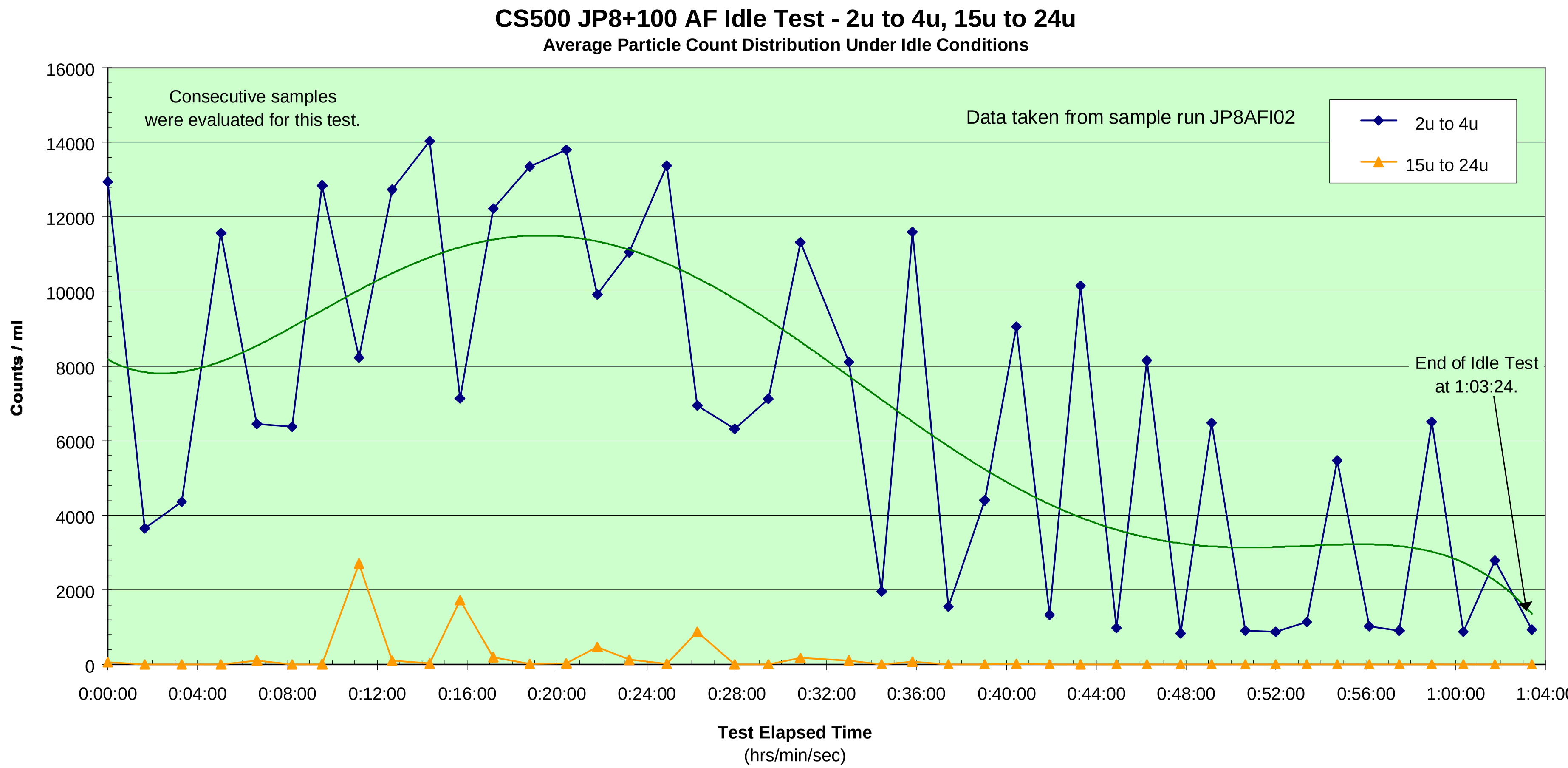
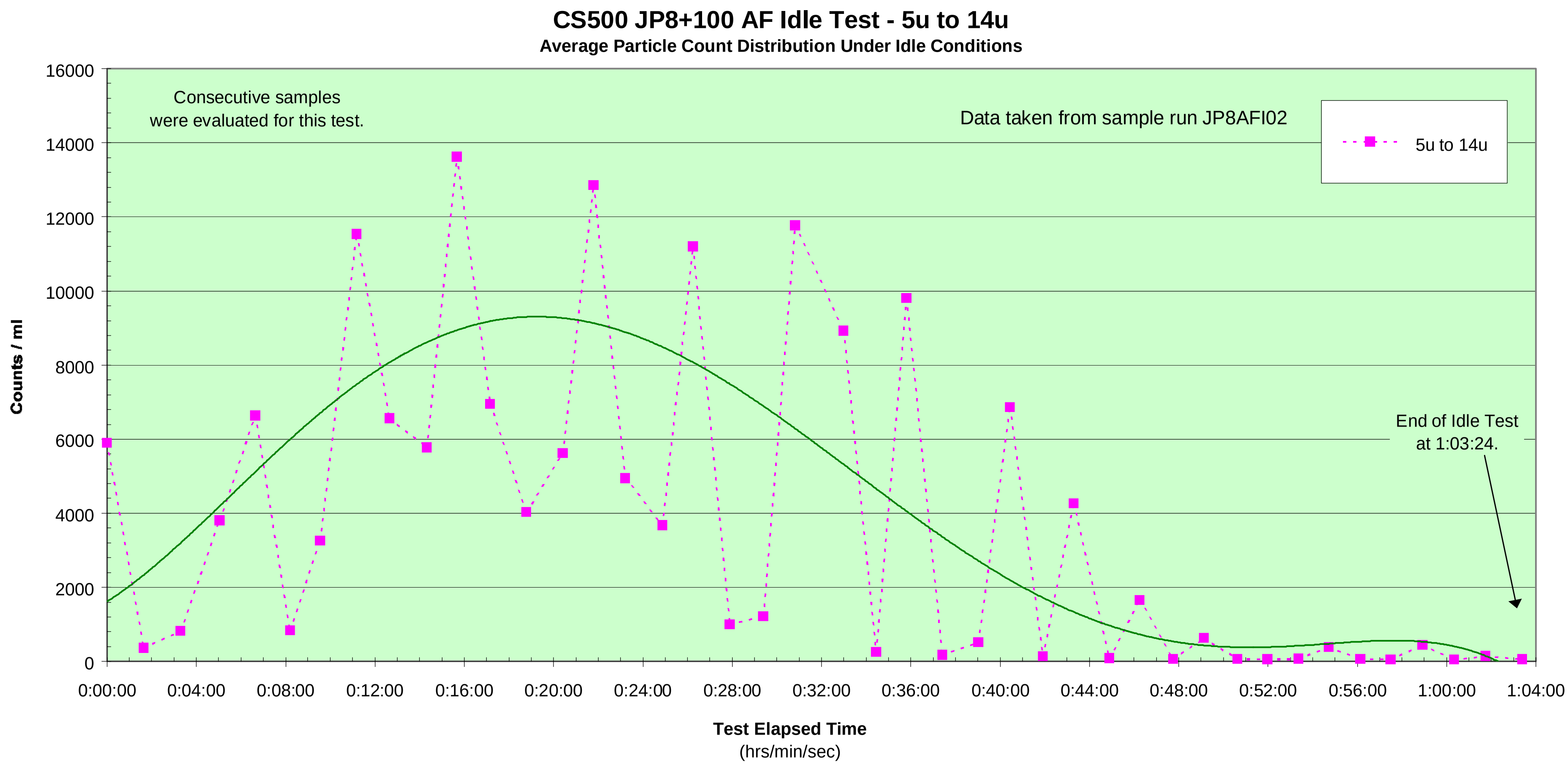

CS500 JP8+100 AF Idle Test - 2u to 4u, 15u to 24u
Average Particle Count Distribution Under Idle Conditions
Consecutive samples were evaluated for this test.
Data taken from sample run JP8AFI02
2u to 4u
15u to 24u
End of Idle Test at 1:03:24.
Counts / ml
0
2000
4000
6000
8000
10000
12000
14000
16000
0:00:00
0:04:00
0:08:00
0:12:00
0:16:00
0:20:00
0:24:00
0:28:00
0:32:00
0:36:00
0:40:00
0:44:00
0:48:00
0:52:00
0:56:00
1:00:00
1:04:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 3B



CS500 JP8+100 AF Idle Test - 5u to 14u
Average Particle Count Distribution Under Idle Conditions
Consecutive samples were evaluated for this test.
Data taken from sample run JP8AFI02
5u to 14u
End of Idle Test at 1:03:24.
Counts / ml
0
2000
4000
6000
8000
10000
12000
14000
16000
0:00:00
0:04:00
0:08:00
0:12:00
0:16:00
0:20:00
0:24:00
0:28:00
0:32:00
0:36:00
0:40:00
0:44:00
0:48:00
0:52:00
0:56:00
1:00:00
1:04:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 3C

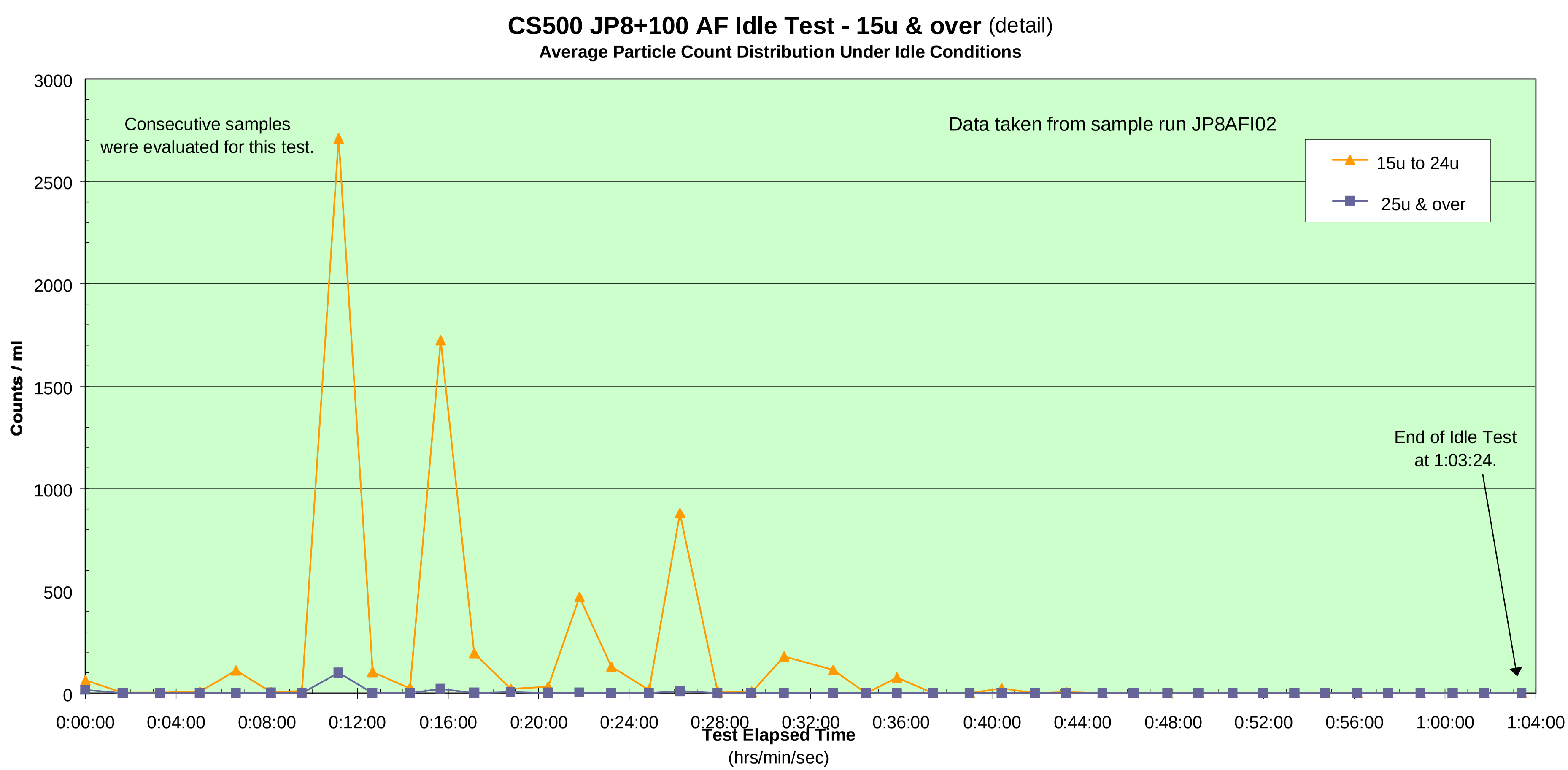

CS500 JP8+100 AF Idle Test - 15u & over (detail)
Average Particle Count Distribution Under Idle Conditions
Counts / ml
3000
2500
2000
1500
1000
500
0
Consecutive samples
were evaluated for this test.
Data taken from sample run JP8AFI02
15u to 24u
25u & over
End of Idle Test
at 1:03:24.
0:00:00
0:04:00
0:08:00
0:12:00
0:16:00
0:20:00
0:24:00
0:28:00
0:32:00
0:36:00
0:40:00
0:44:00
0:48:00
0:52:00
0:56:00
1:00:00
1:04:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 4A

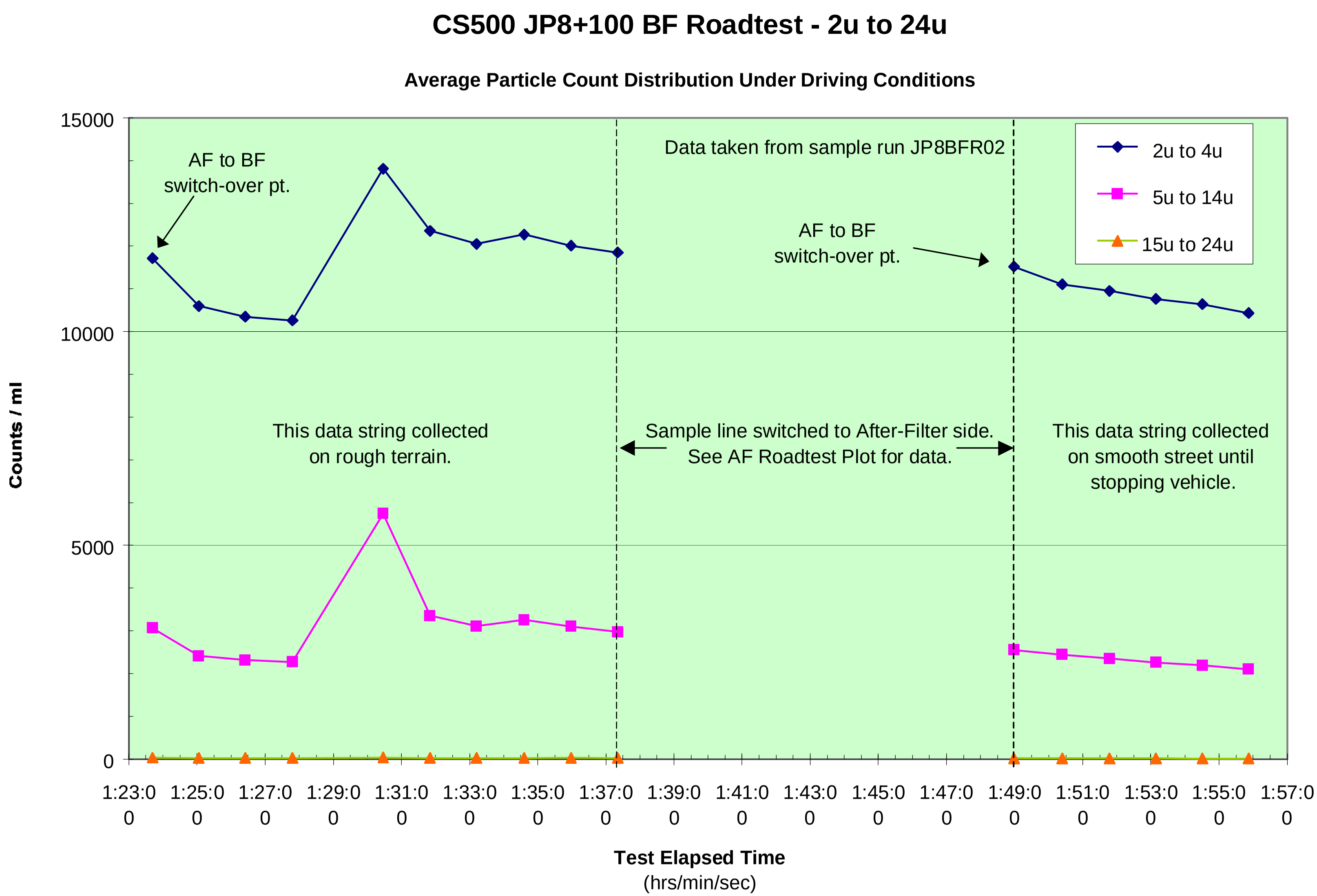

CS500 JP8+100 BF Roadtest - 2u to 24u
Average Particle Count Distribution Under Driving Conditions
Counts / ml
15000
10000
5000
0
AF to BF
switch-over pt.
Data taken from sample run JP8BFR02
AF to BF
switch-over pt.
2u to 4u
5u to 14u
15u to 24u
This data string collected
on rough terrain.
Sample line switched to After-Filter side.
See AF Roadtest Plot for data.
This data string collected
on smooth street until
stopping vehicle.
1:23:00
1:25:00
1:27:00
1:29:00
1:31:00
1:33:00
1:35:00
1:37:00
1:39:00
1:41:00
1:43:00
1:45:00
1:47:00
1:49:00
1:51:00
1:53:00
1:55:00
1:57:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 4b

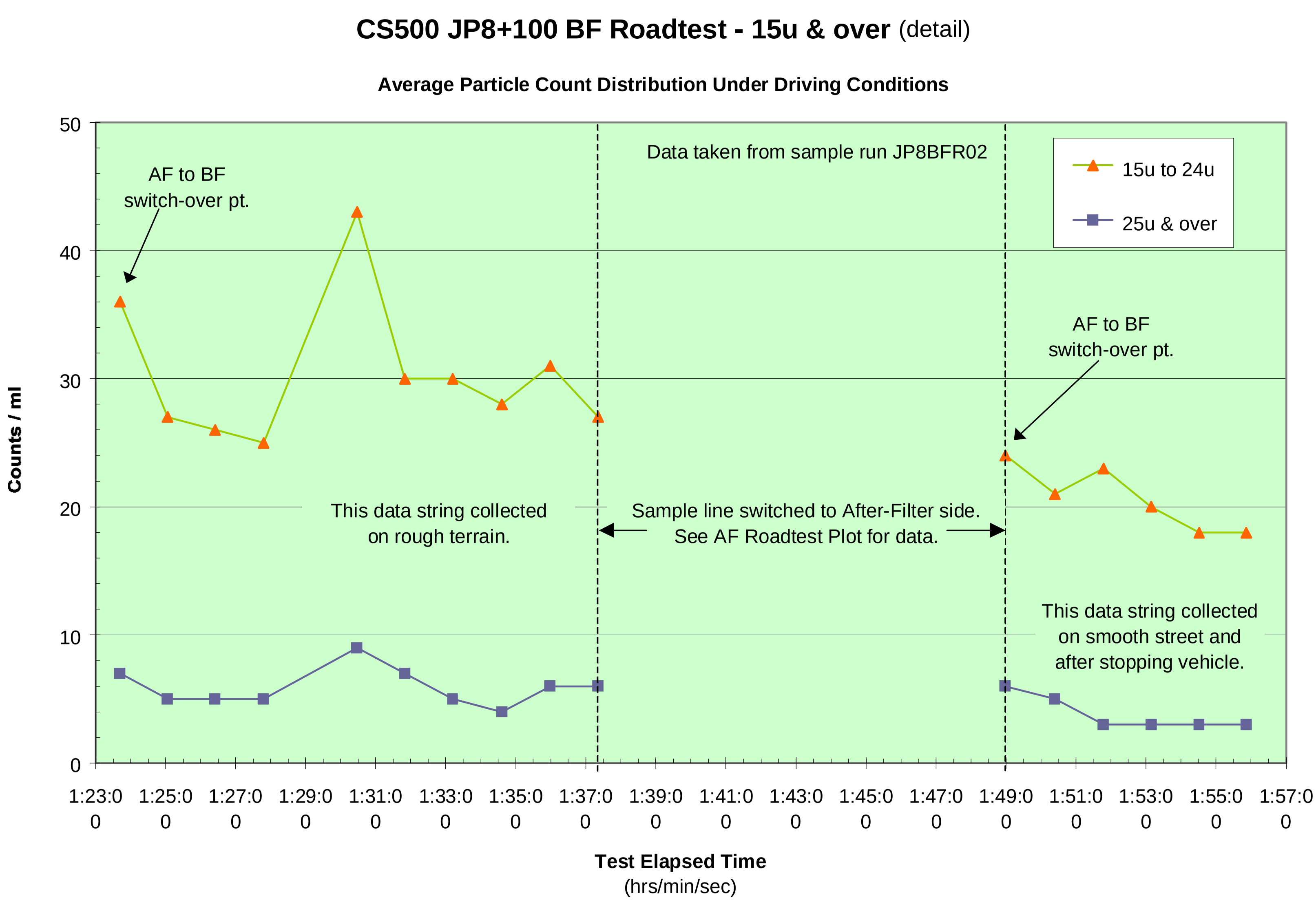
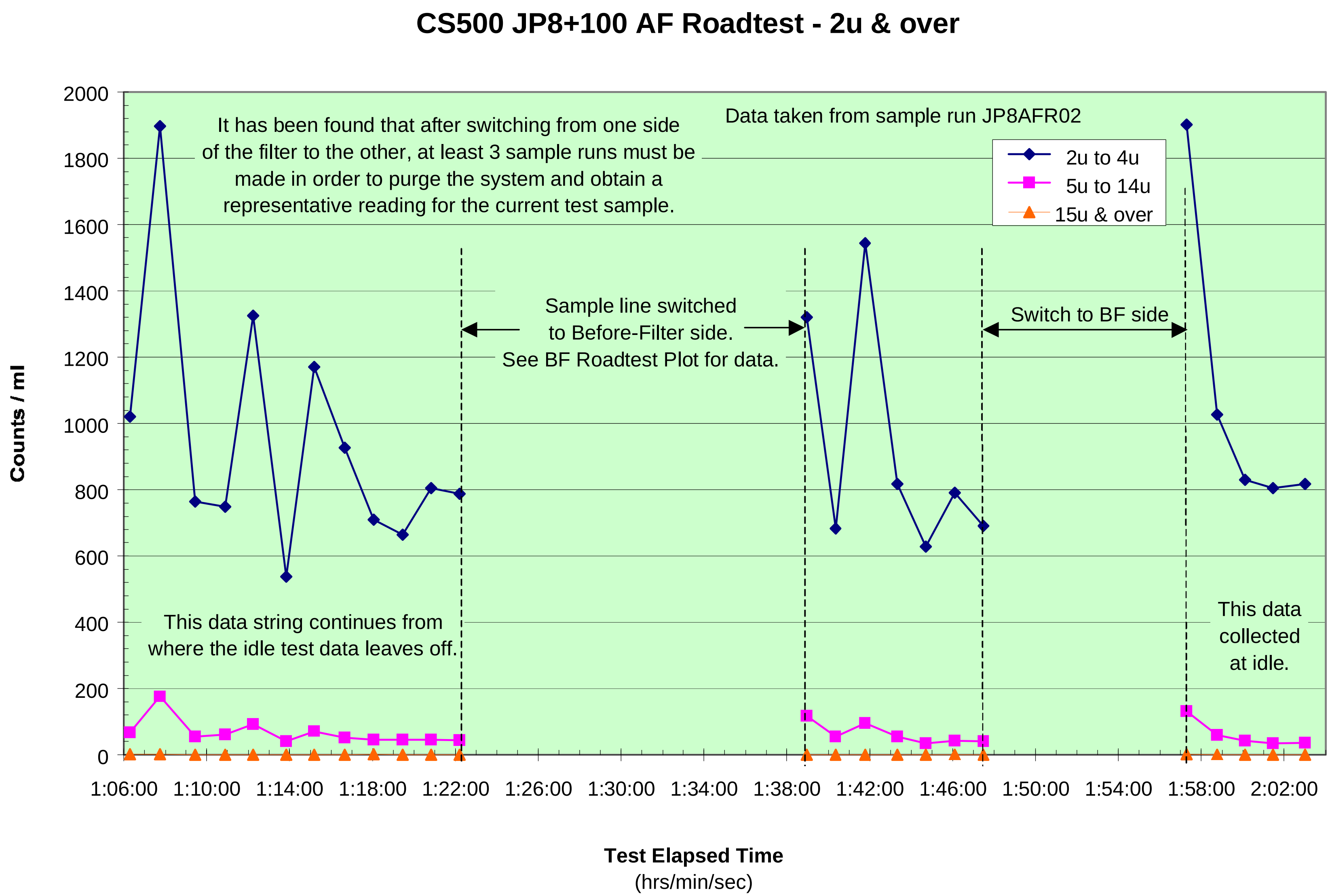

CS500 JP8+100 BF Roadtest - 15u & over (detail)
Average Particle Count Distribution Under Driving Conditions
Counts / ml
50
40
30
20
10
0
1:23:00
1:25:00
1:27:00
1:29:00
1:31:00
1:33:00
1:35:00
1:37:00
1:39:00
1:41:00
1:43:00
1:45:00
1:47:00
1:49:00
1:51:00
1:53:00
1:55:00
1:57:00
Test Elapsed Time
(hrs/min/sec)
15u to 24u
25u & over
AF to BF switch-over pt.
This data string collected on rough terrain.
Data taken from sample run JP8BFR02
Sample line switched to After-Filter side. See AF Roadtest Plot for data.
AF to BF switch-over pt.
This data string collected on smooth street and after stopping vehicle.

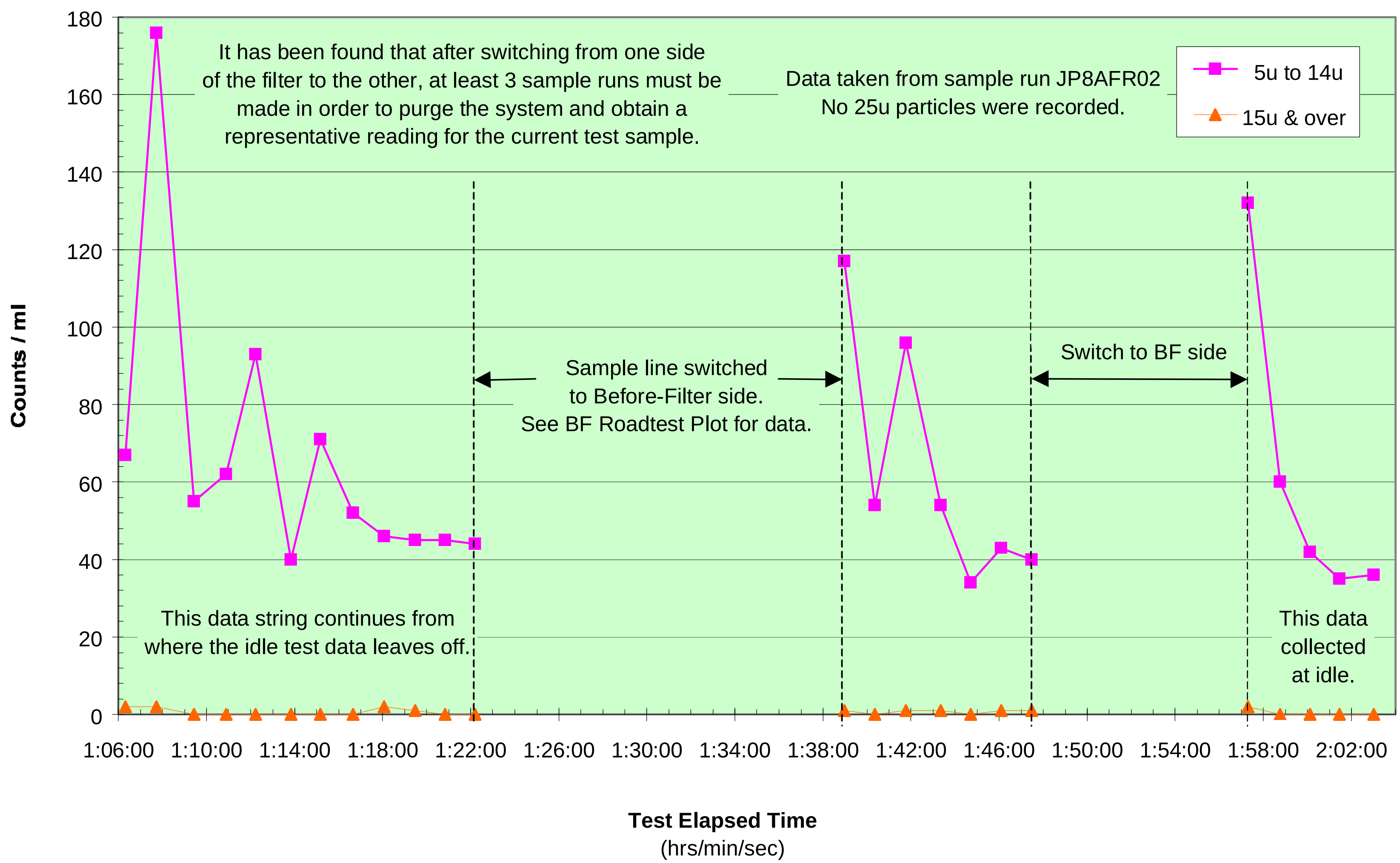
FIGURE 4C



CS500 JP8+100 AF Roadtest - 2u & over
It has been found that after switching from one side of the filter to the other, at least 3 sample runs must be made in order to purge the system and obtain a representative reading for the current test sample.
Data taken from sample run JP8AFR02
2u to 4u
5u to 14u
15u & over
Sample line switched to Before-Filter side.
See BF Roadtest Plot for data.
Switch to BF side
This data string continues from where the idle test data leaves off.
This data collected at idle.
Counts / ml
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1:06:00
1:10:00
1:14:00
1:18:00
1:22:00
1:26:00
1:30:00
1:34:00
1:38:00
1:42:00
1:46:00
1:50:00
1:54:00
1:58:00
2:02:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 4D

CS500 JP8+100 AF Roadtest - 5u & over (detail)



APPENDIX C

CS522 5-TON TRUCK TEST DATA

FIGURE 1A

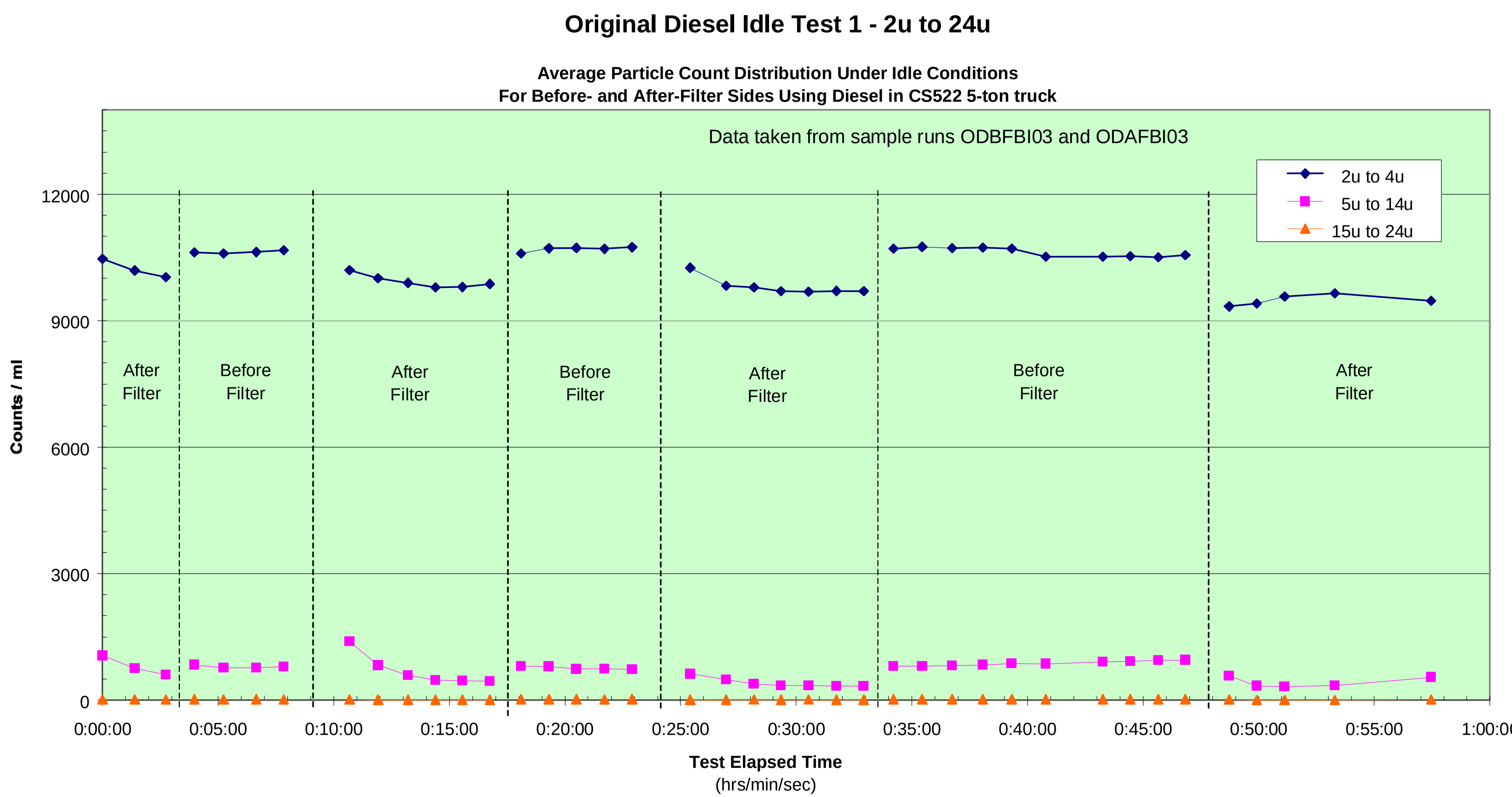
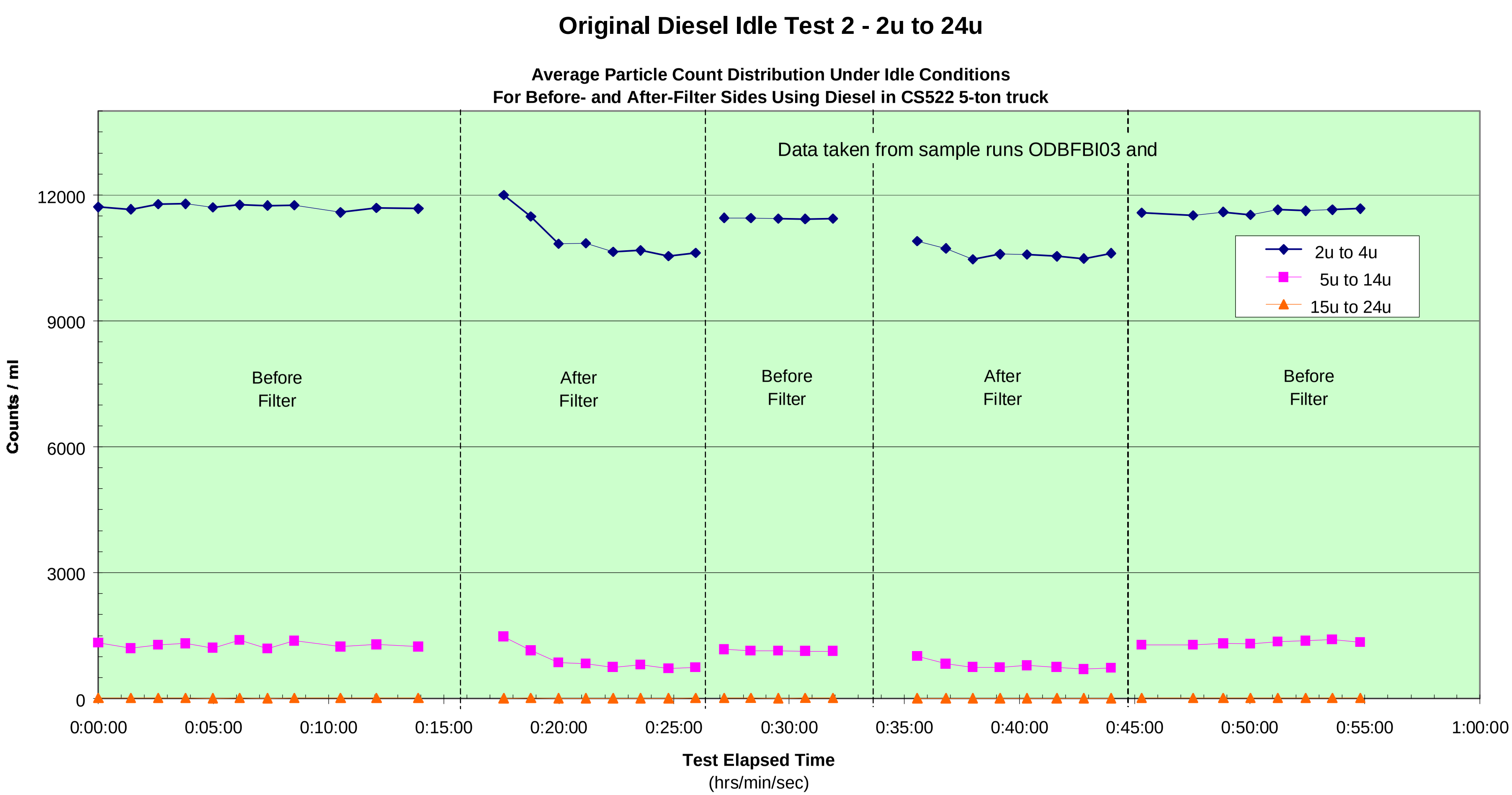
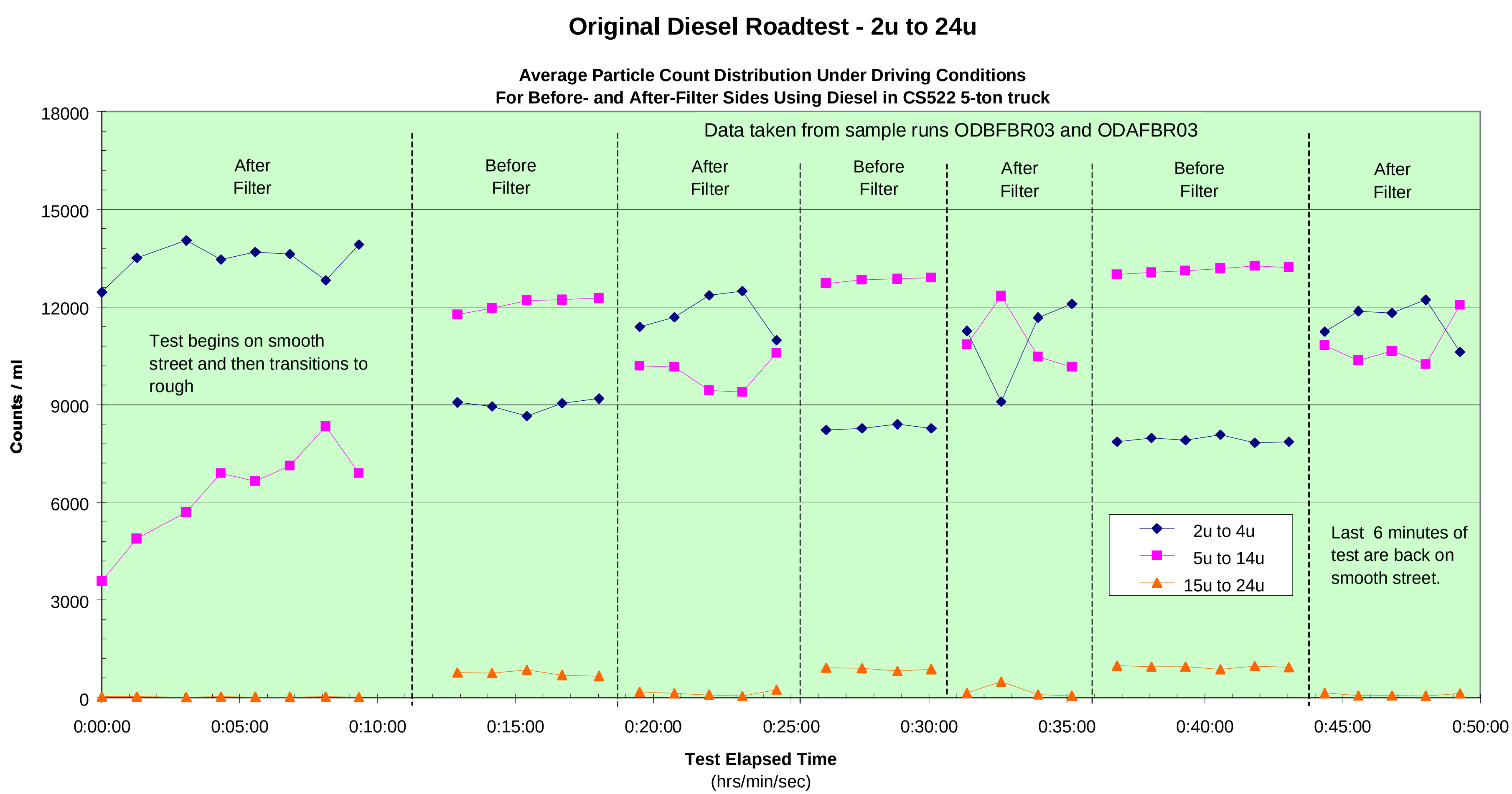

Original Diesel Idle Test 1 - 2u to 24u
Average Particle Count Distribution Under Idle Conditions
For Before- and After-Filter Sides Using Diesel in CS522 5-ton truck
Data taken from sample runs ODBFBI03 and ODAFBI03
2u to 4u
5u to 14u
15u to 24u
After Filter
Before Filter
After Filter
Before Filter
After Filter
Before Filter
After Filter
Counts / ml
12000
9000
6000
3000
0
0:00:00
0:05:00
0:10:00
0:15:00
0:20:00
0:25:00
0:30:00
0:35:00
0:40:00
0:45:00
0:50:00
0:55:00
1:00:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 1B



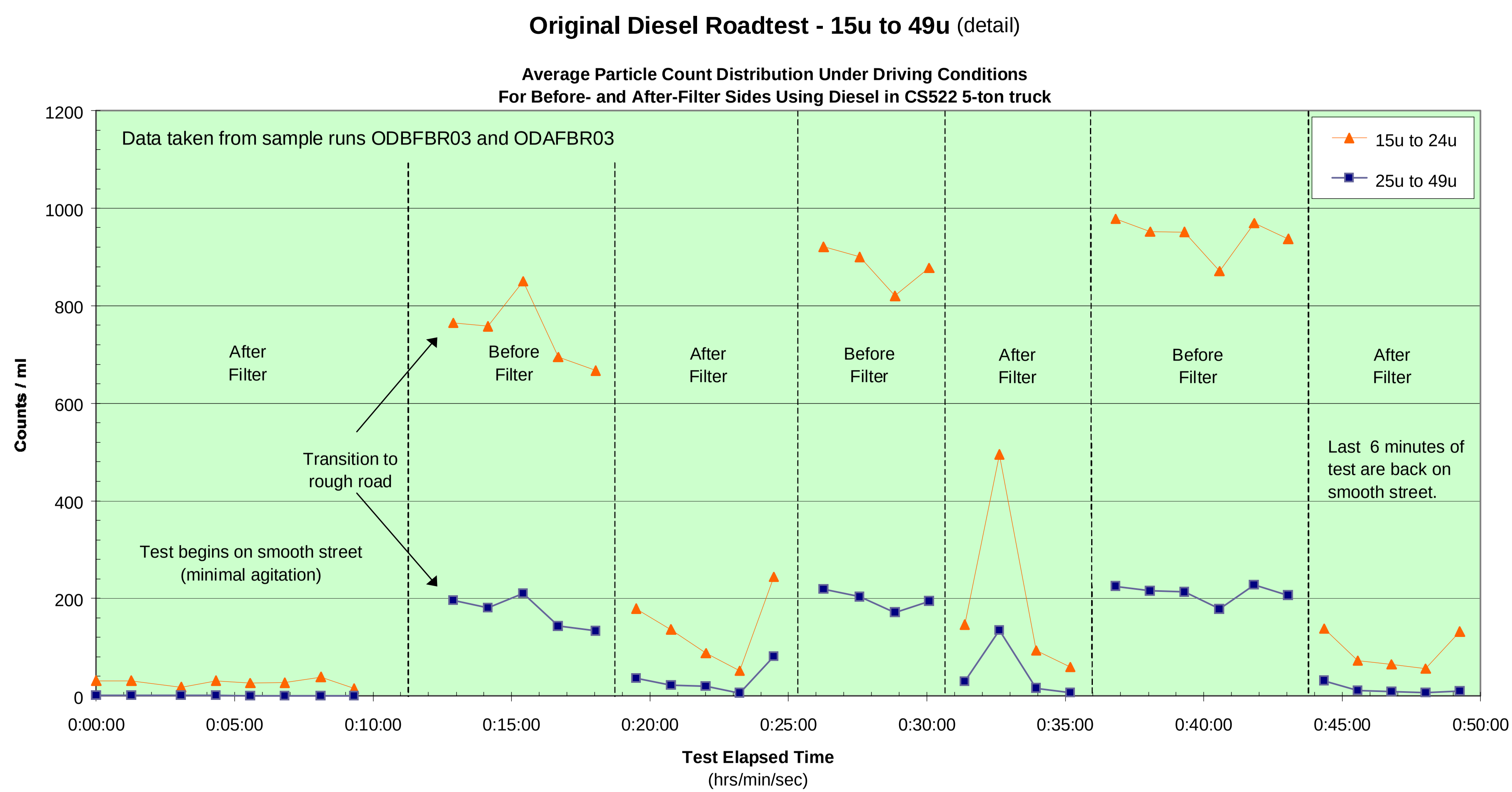
Original Diesel Idle Test 2 - 2u to 24u
Average Particle Count Distribution Under Idle Conditions
For Before- and After-Filter Sides Using Diesel in CS522 5-ton truck
Data taken from sample runs ODBFBI03 and
Counts / ml
12000
9000
6000
3000
0
Before Filter
After Filter
Before Filter
After Filter
Before Filter
2u to 4u
5u to 14u
15u to 24u
0:00:00
0:05:00
0:10:00
0:15:00
0:20:00
0:25:00
0:30:00
0:35:00
0:40:00
0:45:00
0:50:00
0:55:00
1:00:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 2A



Original Diesel Roadtest - 2u to 24u
Average Particle Count Distribution Under Driving Conditions
For Before- and After-Filter Sides Using Diesel in CS522 5-ton truck
Data taken from sample runs ODBFBR03 and ODAFBR03
After Filter
Before Filter
After Filter
Before Filter
After Filter
Before Filter
After Filter
Test begins on smooth street and then transitions to rough
Last 6 minutes of test are back on smooth street.
2u to 4u
5u to 14u
15u to 24u
Counts / ml
18000
15000
12000
9000
6000
3000
0
0:00:00
0:05:00
0:10:00
0:15:00
0:20:00
0:25:00
0:30:00
0:35:00
0:40:00
0:45:00
0:50:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 2B



Original Diesel Roadtest - 15u to 49u (detail)
Average Particle Count Distribution Under Driving Conditions
For Before- and After-Filter Sides Using Diesel in CS522 5-ton truck
Data taken from sample runs ODBFBR03 and ODAFBR03
15u to 24u
25u to 49u
After Filter
Before Filter
After Filter
Before Filter
After Filter
Before Filter
After Filter
Transition to rough road
Test begins on smooth street (minimal agitation)
Last 6 minutes of test are back on smooth street.
Counts / ml
0
200
400
600
800
1000
1200
Test Elapsed Time
(hrs/min/sec)
0:00:00
0:05:00
0:10:00
0:15:00
0:20:00
0:25:00
0:30:00
0:35:00
0:40:00
0:45:00
0:50:00

FIGURE 2C

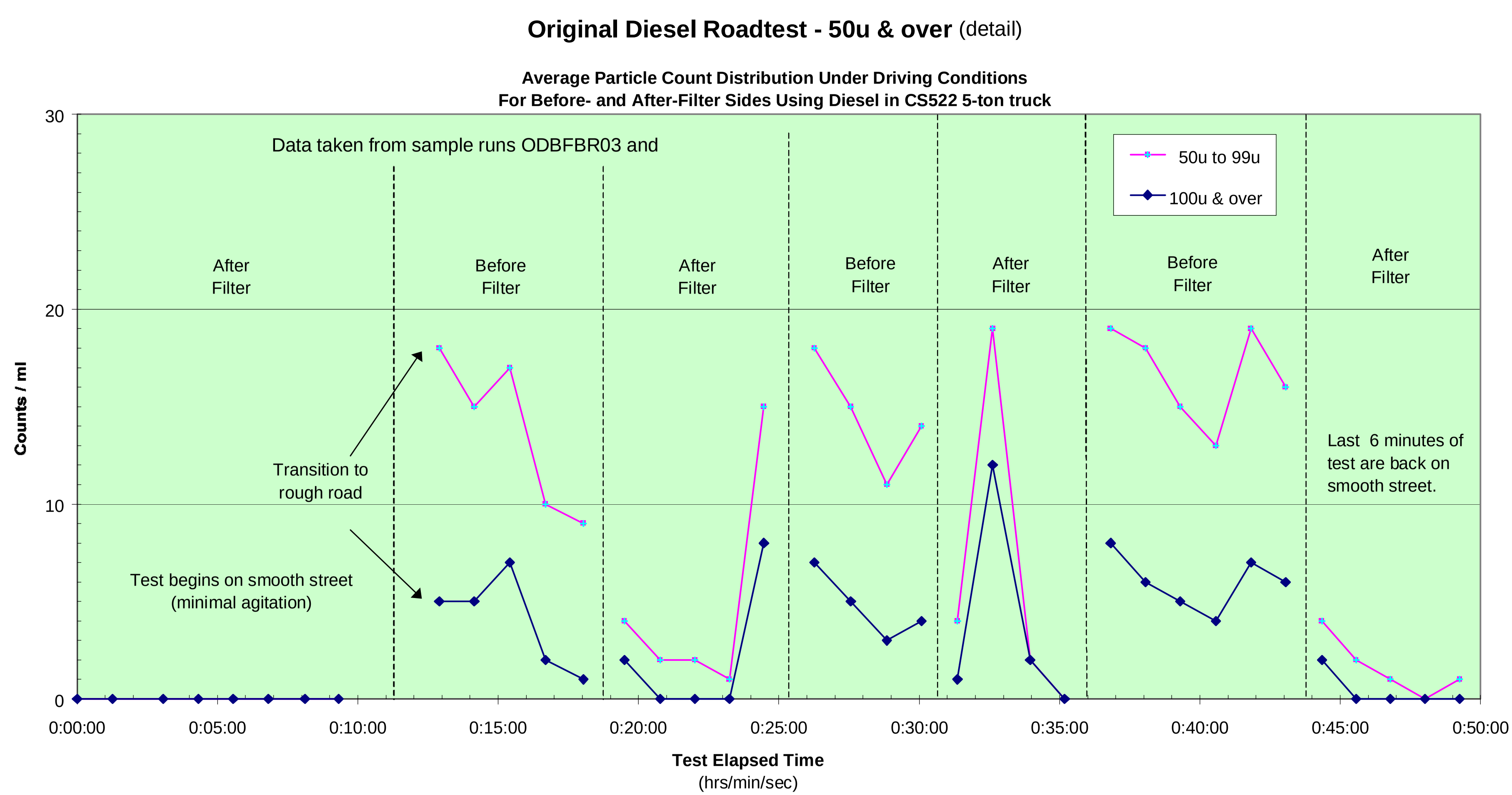

Original Diesel Roadtest - 50u & over (detail)
Average Particle Count Distribution Under Driving Conditions
For Before- and After-Filter Sides Using Diesel in CS522 5-ton truck
Data taken from sample runs ODBFBR03 and
50u to 99u
100u & over
After Filter
Before Filter
After Filter
Before Filter
After Filter
Before Filter
After Filter
Transition to rough road
Test begins on smooth street (minimal agitation)
Last 6 minutes of test are back on smooth street.
Counts / ml
30
20
10
0
0:00:00
0:05:00
0:10:00
0:15:00
0:20:00
0:25:00
0:30:00
0:35:00
0:40:00
0:45:00
0:50:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 3A

JP8+100 Idle Test - 2u to 24u

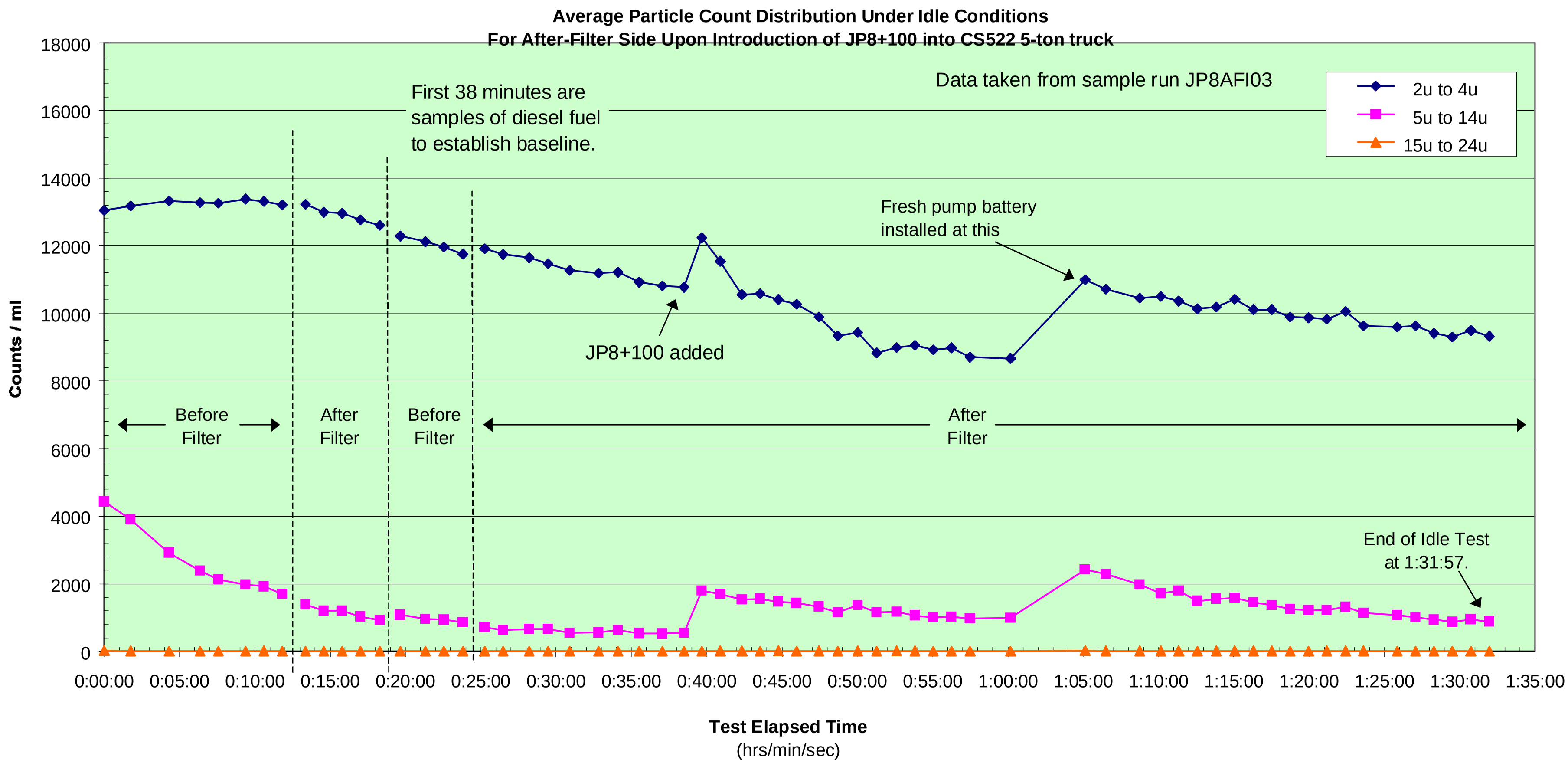


FIGURE 3B

JP8+100 Idle Test - 15u to 49u (detail)

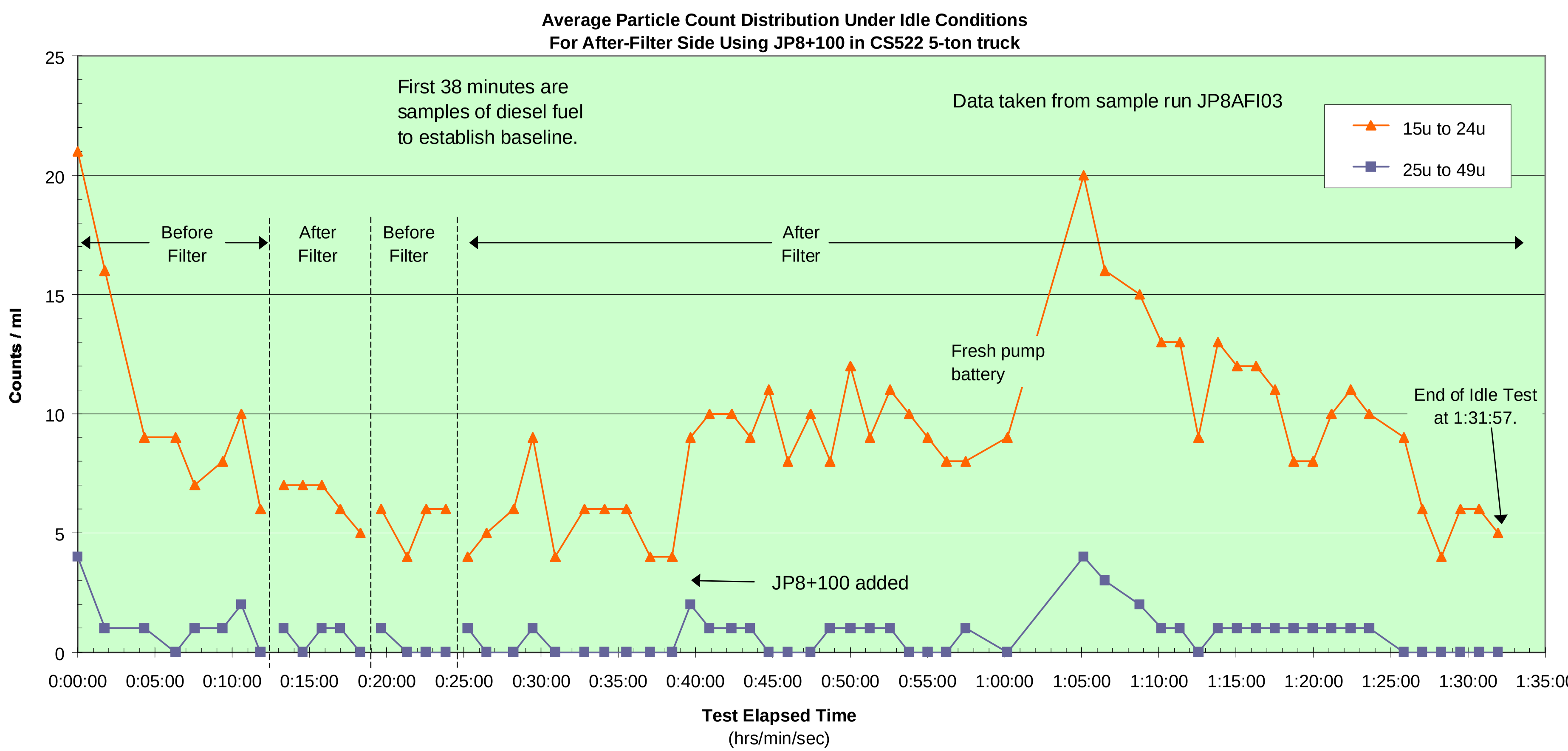


FIGURE 4A

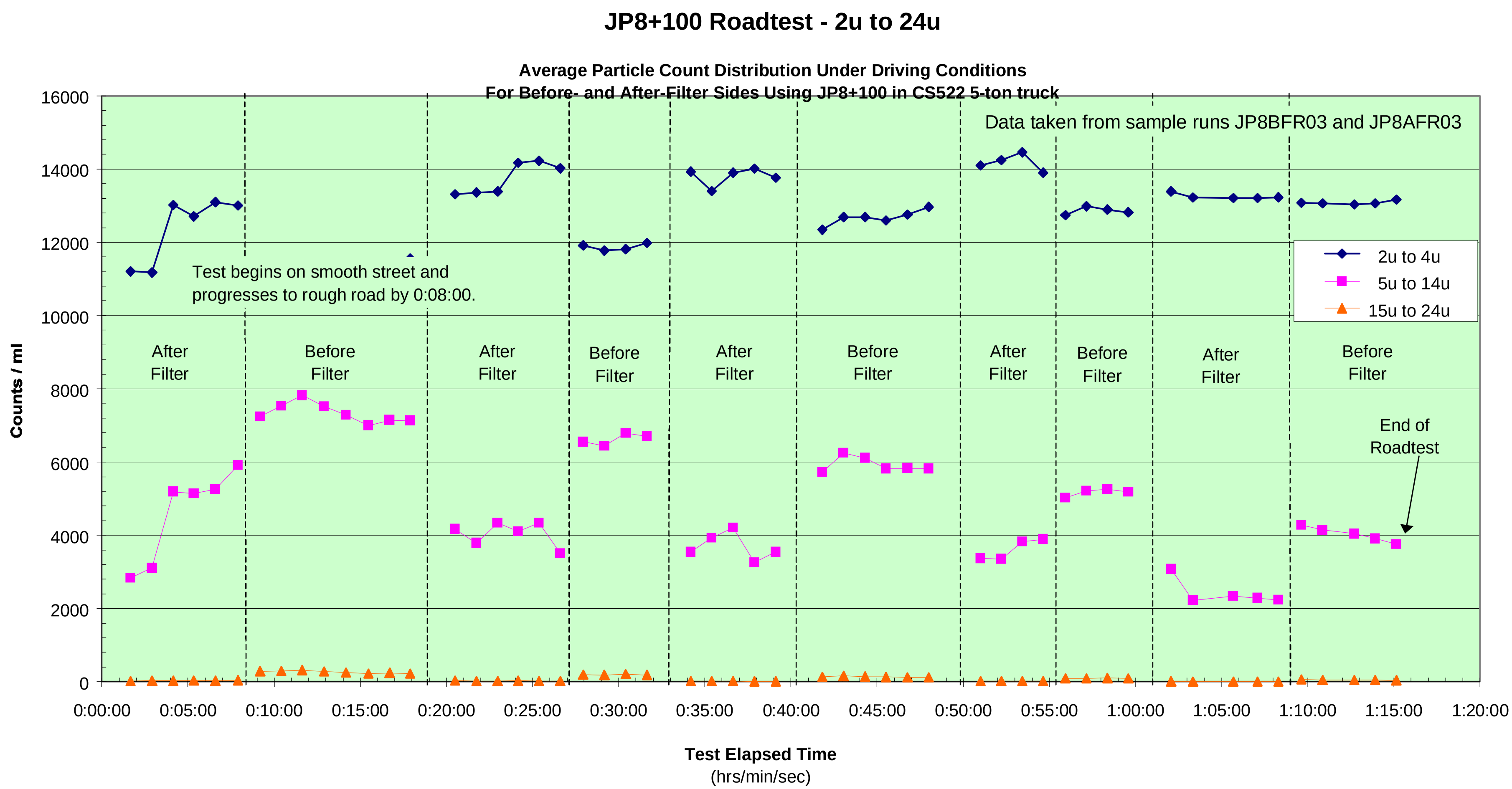
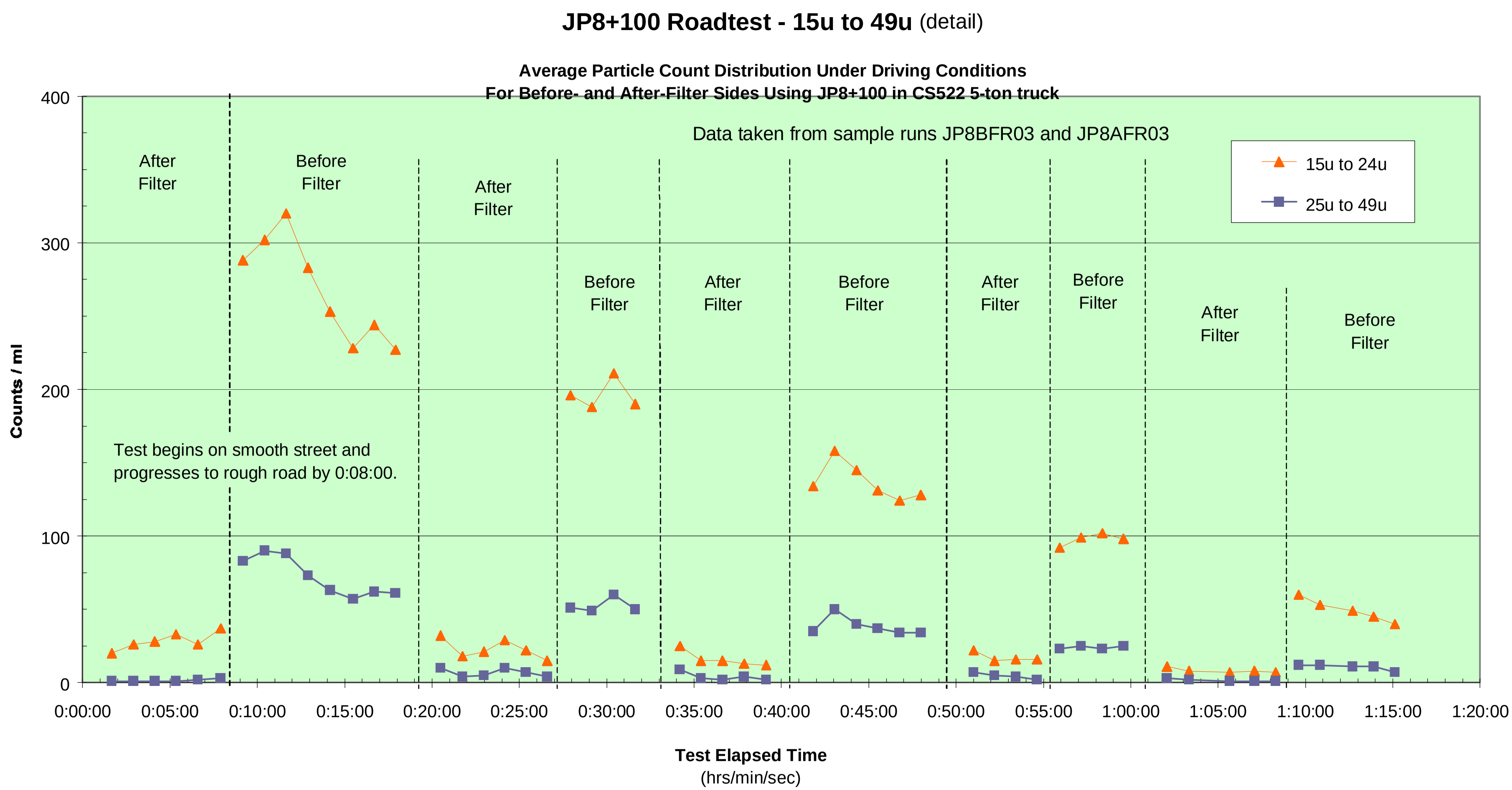
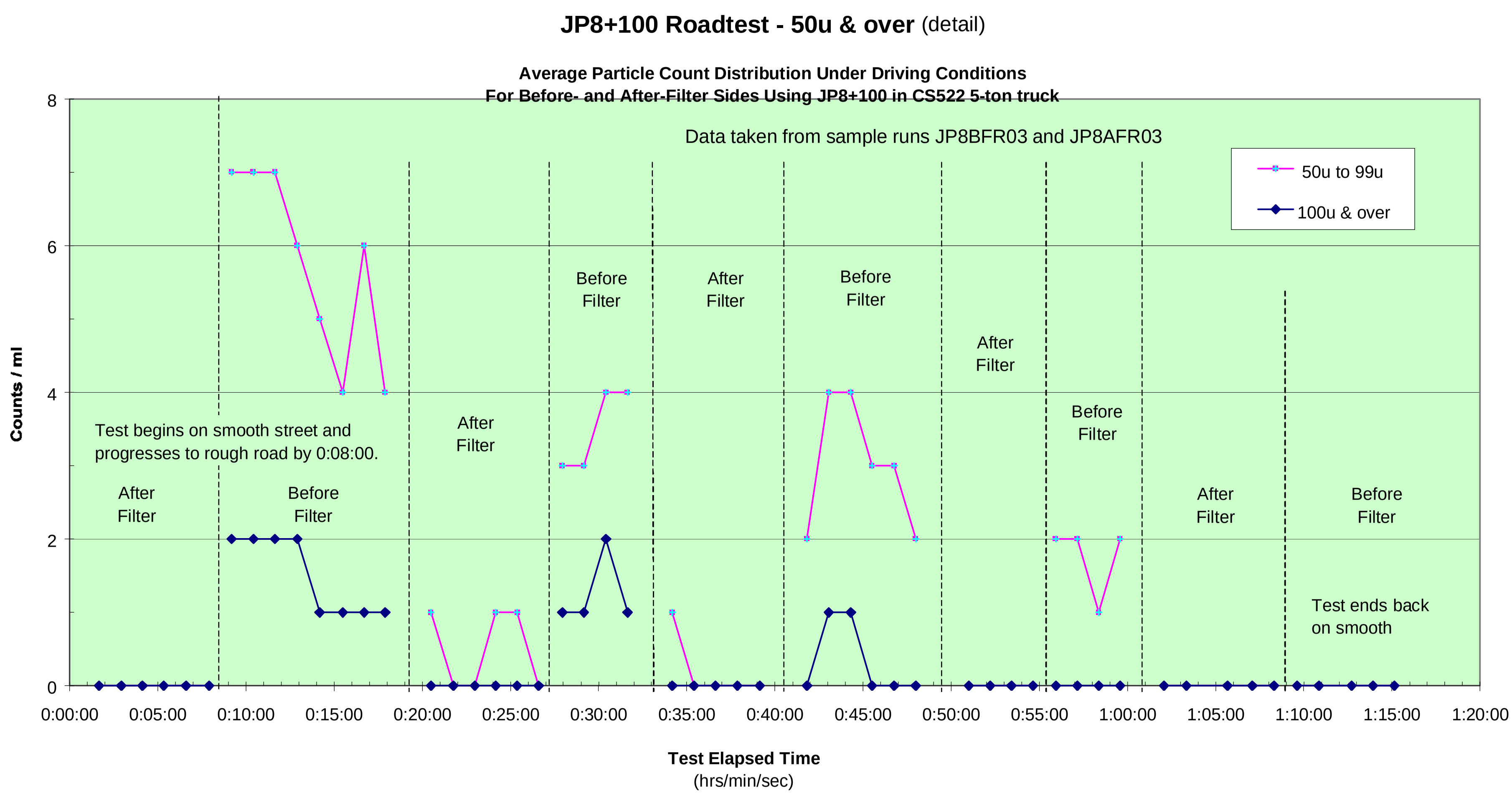

JP8+100 Roadtest - 2u to 24u
Average Particle Count Distribution Under Driving Conditions
For Before- and After-Filter Sides Using JP8+100 in CS522 5-ton truck
Data taken from sample runs JP8BFR03 and JP8AFR03
Test begins on smooth street and progresses to rough road by 0:08:00.
After Filter
Before Filter
End of Roadtest
2u to 4u
5u to 14u
15u to 24u
Counts / ml
Test Elapsed Time
(hrs/min/sec)
0
2000
4000
6000
8000
10000
12000
14000
16000
0:00:00
0:05:00
0:10:00
0:15:00
0:20:00
0:25:00
0:30:00
0:35:00
0:40:00
0:45:00
0:50:00
0:55:00
1:00:00
1:05:00
1:10:00
1:15:00
1:20:00

FIGURE 4B



JP8+100 Roadtest - 15u to 49u (detail)
Average Particle Count Distribution Under Driving Conditions
For Before- and After-Filter Sides Using JP8+100 in CS522 5-ton truck
Data taken from sample runs JP8BFR03 and JP8AFR03
15u to 24u
25u to 49u
After Filter
Before Filter
After Filter
Before Filter
After Filter
Before Filter
After Filter
Before Filter
After Filter
Before Filter
Test begins on smooth street and progresses to rough road by 0:08:00.
Counts / ml
400
300
200
100
0
0:00:00
0:05:00
0:10:00
0:15:00
0:20:00
0:25:00
0:30:00
0:35:00
0:40:00
0:45:00
0:50:00
0:55:00
1:00:00
1:05:00
1:10:00
1:15:00
1:20:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 4C


JP8+100 Roadtest - 50u & over (detail)
Average Particle Count Distribution Under Driving Conditions
For Before- and After-Filter Sides Using JP8+100 in CS522 5-ton truck
Data taken from sample runs JP8BFR03 and JP8AFR03
50u to 99u
100u & over
Test begins on smooth street and
progresses to rough road by 0:08:00.
After
Filter
Before
Filter
After
Filter
Before
Filter
After
Filter
Before
Filter
After
Filter
Before
Filter
After
Filter
Before
Filter
Test ends back
on smooth
Counts / ml
0
2
4
6
8
0:00:00
0:05:00
0:10:00
0:15:00
0:20:00
0:25:00
0:30:00
0:35:00
0:40:00
0:45:00
0:50:00
0:55:00
1:00:00
1:05:00
1:10:00
1:15:00
1:20:00
Test Elapsed Time
(hrs/min/sec)

APPENDIX D

CS200 HMMWV TEST DATA

FIGURE 1A

Original Diesel Idle Test - 3u to 14u
Before-Filter Side

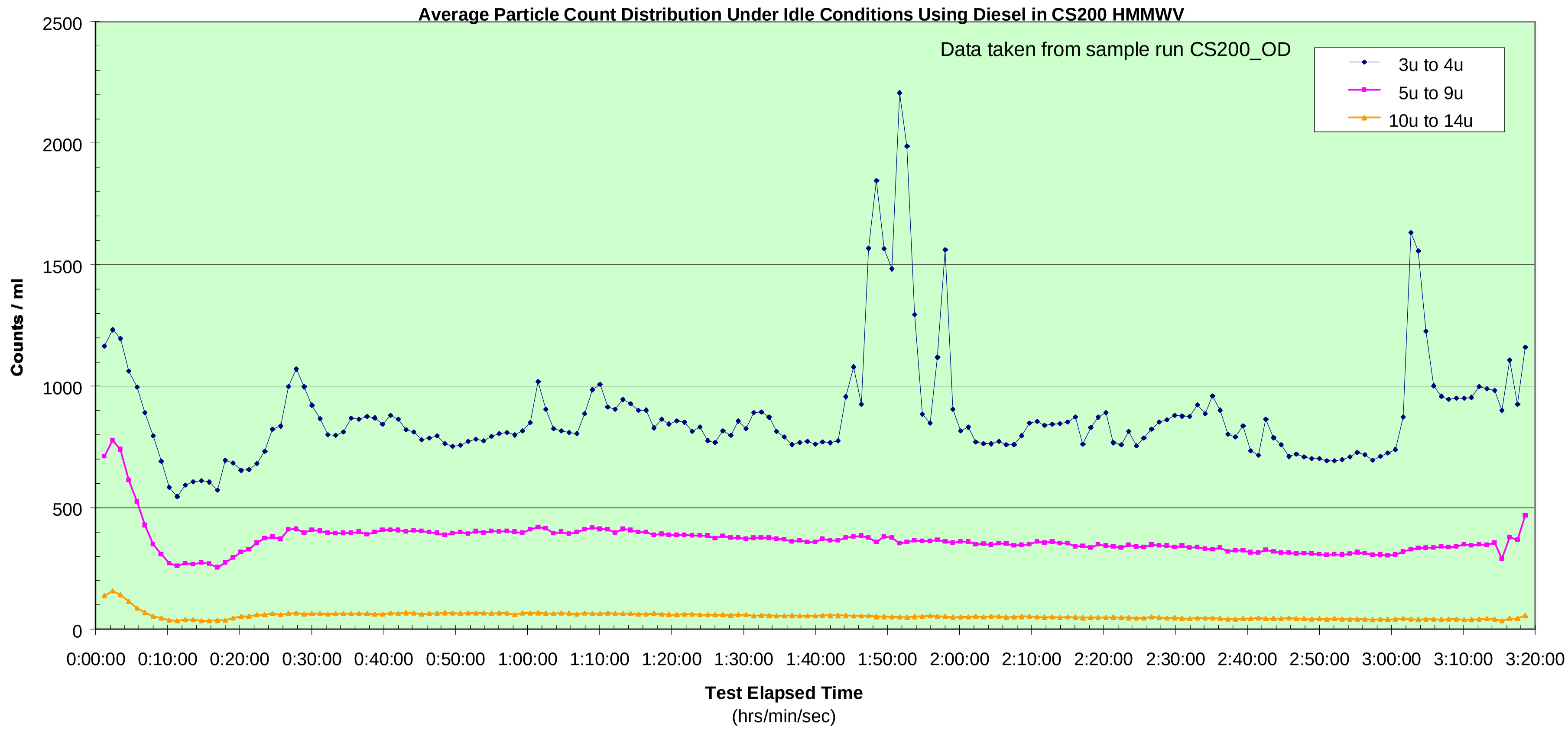


FIGURE 1B

Original Diesel Idle Test - 10u, 15u, 20u (detail)
Before-Filter Side

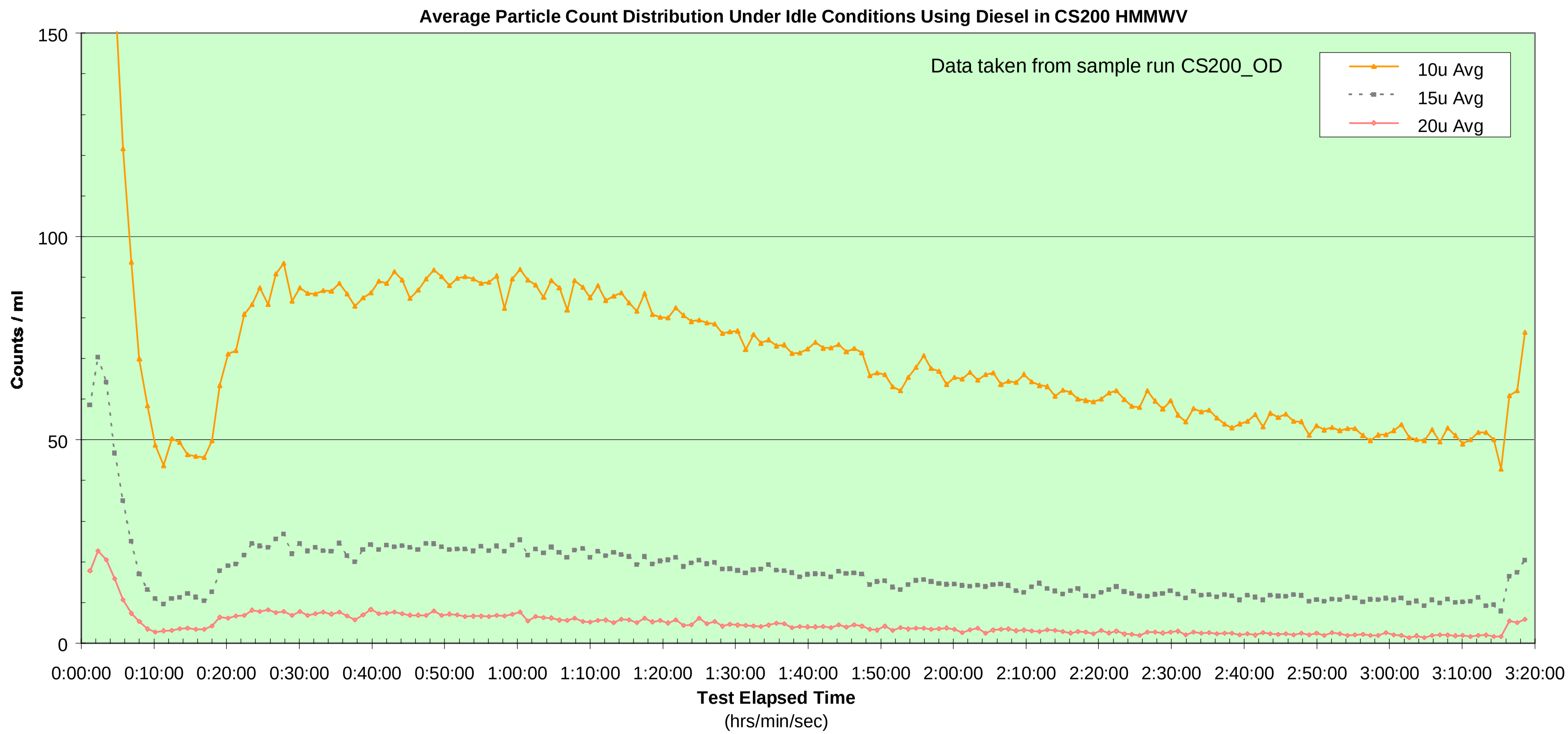


FIGURE 1C

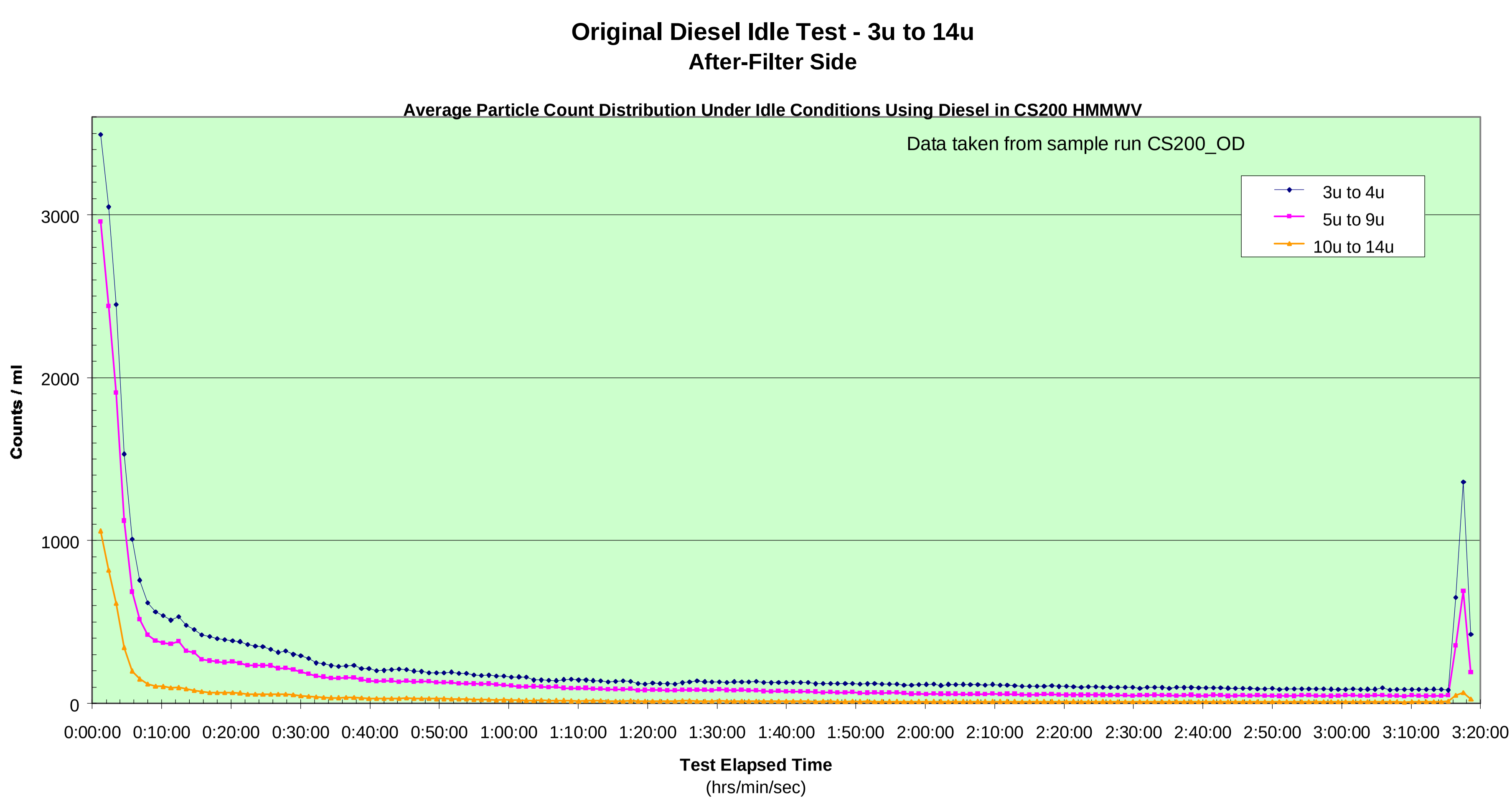

Original Diesel Idle Test - 3u to 14u
After-Filter Side
Average Particle Count Distribution Under Idle Conditions Using Diesel in CS200 HMMWV
Data taken from sample run CS200_OD
3u to 4u
5u to 9u
10u to 14u
Counts / ml
0
1000
2000
3000
0:00:00
0:10:00
0:20:00
0:30:00
0:40:00
0:50:00
1:00:00
1:10:00
1:20:00
1:30:00
1:40:00
1:50:00
2:00:00
2:10:00
2:20:00
2:30:00
2:40:00
2:50:00
3:00:00
3:10:00
3:20:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 1D

Original Diesel Idle Test - 3u to 14u (detail)
After-Filter Side - after 0:15:00

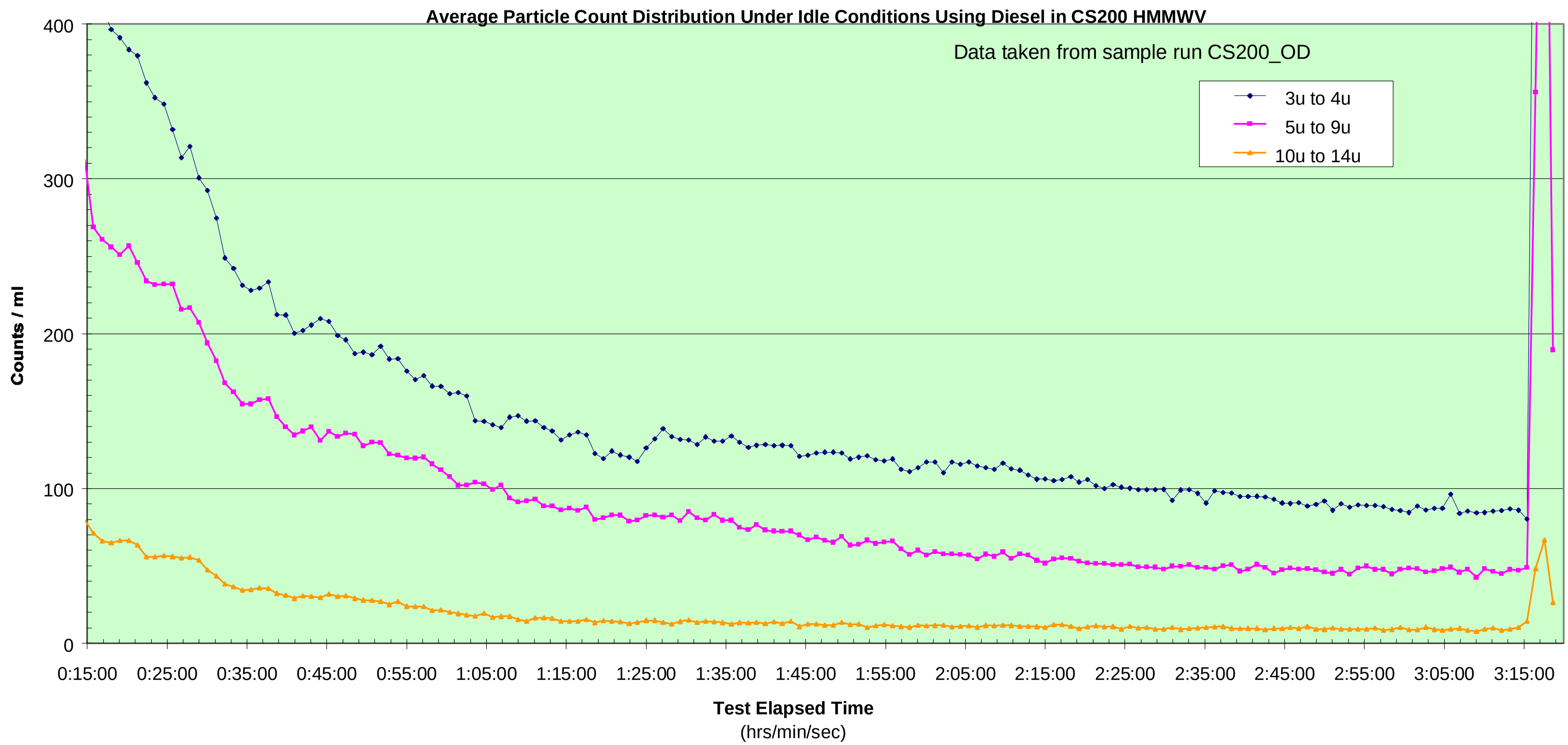


FIGURE 1E

Original Diesel Idle Test - 10u & over (detail)
After-Filter Side : Full Test Span

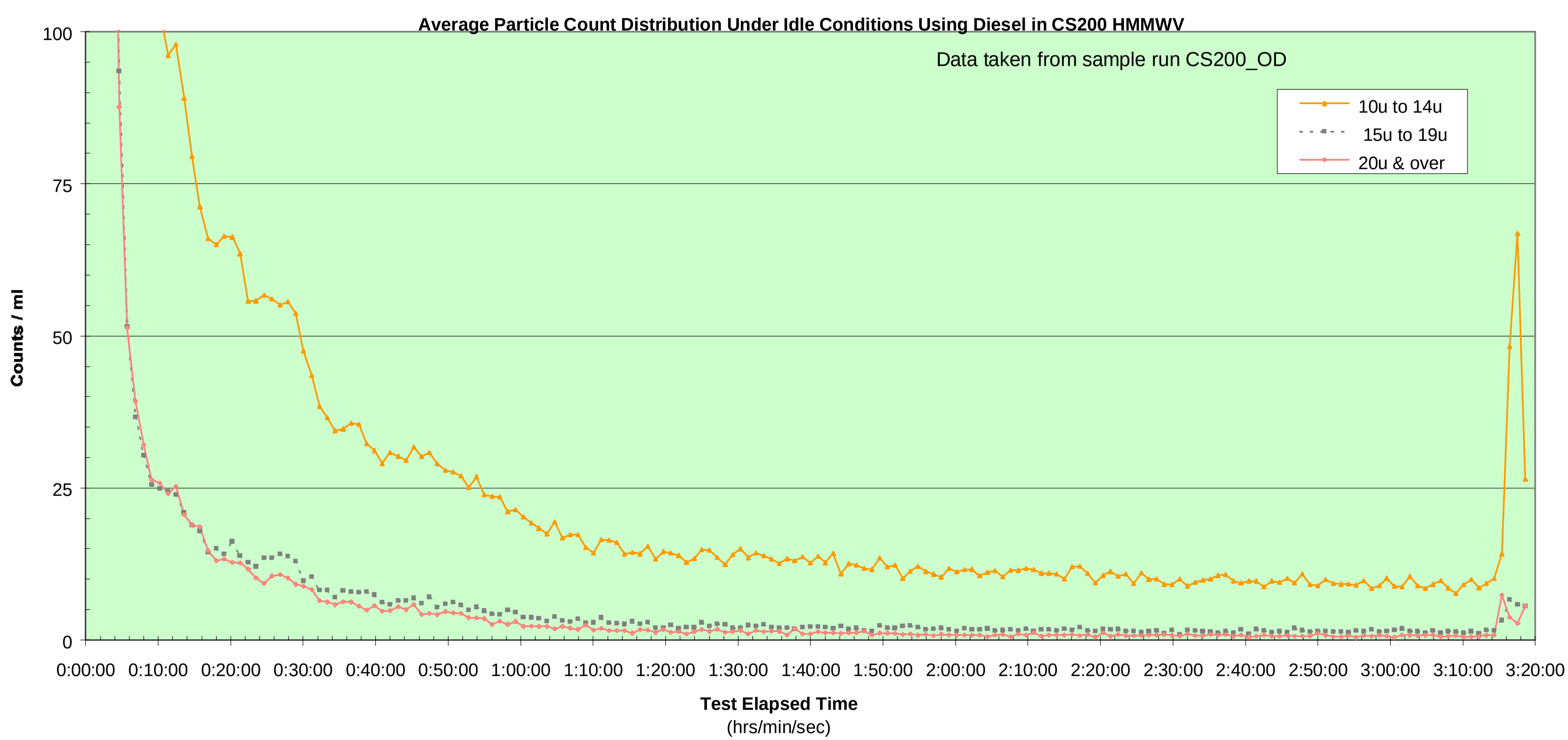
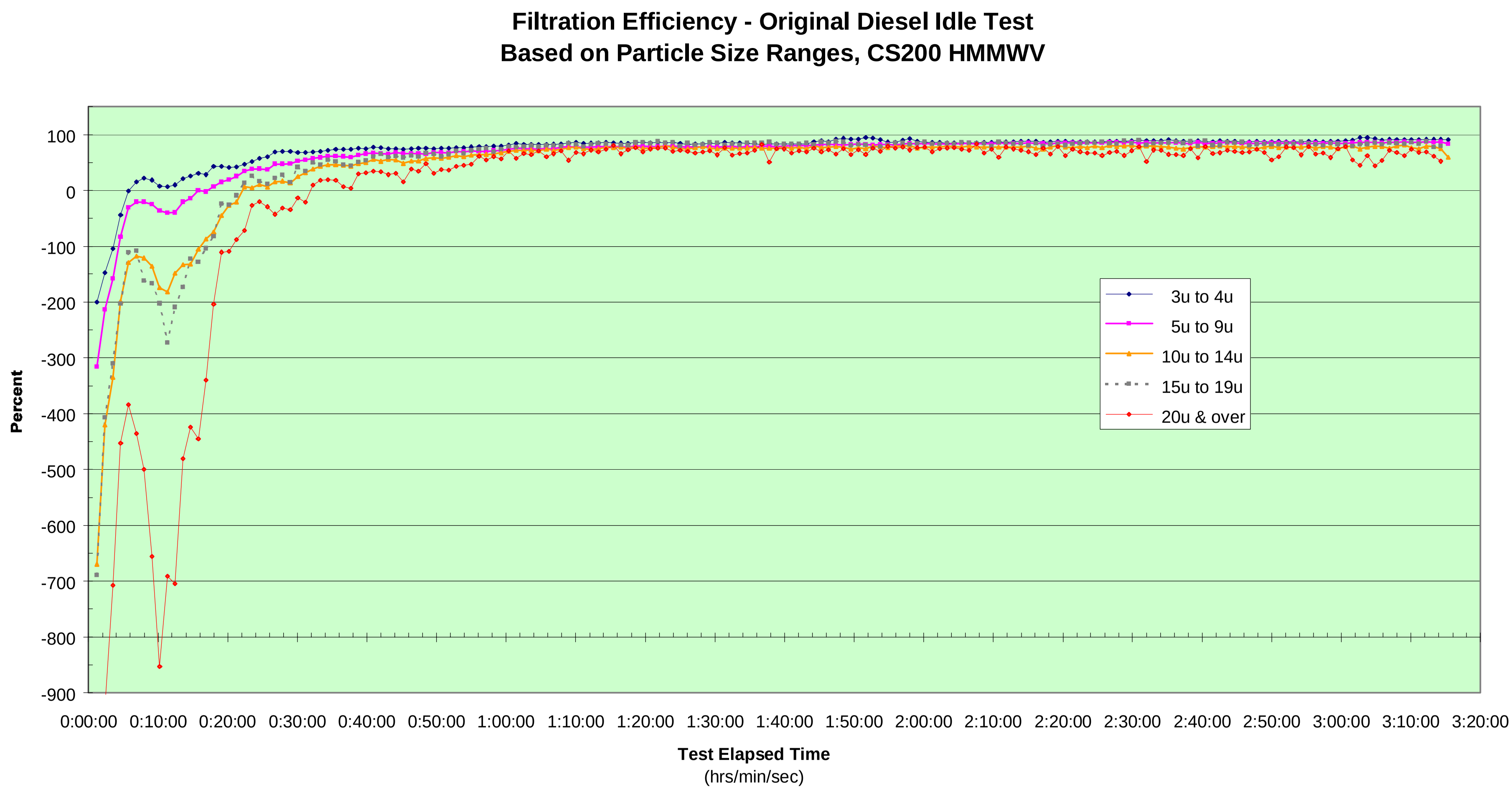


FIGURE 1F



Filtration Efficiency - Original Diesel Idle Test
Based on Particle Size Ranges, CS200 HMMWV
Percent
100
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
0:00:00
0:10:00
0:20:00
0:30:00
0:40:00
0:50:00
1:00:00
1:10:00
1:20:00
1:30:00
1:40:00
1:50:00
2:00:00
2:10:00
2:20:00
2:30:00
2:40:00
2:50:00
3:00:00
3:10:00
3:20:00
Test Elapsed Time
(hrs/min/sec)
3u to 4u
5u to 9u
10u to 14u
15u to 19u
20u & over

FIGURE 1G

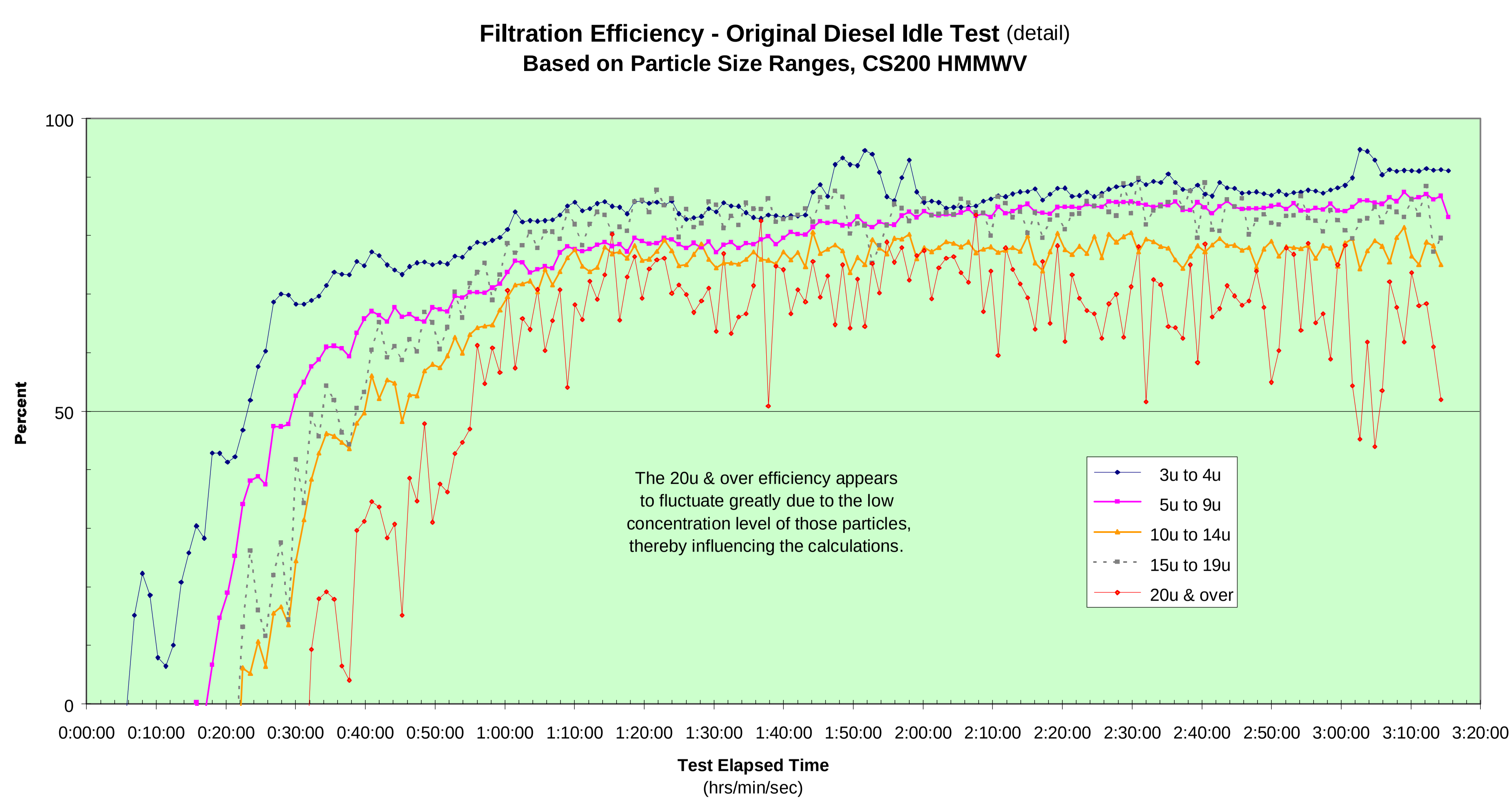

Filtration Efficiency - Original Diesel Idle Test (detail)
Based on Particle Size Ranges, CS200 HMMWV
100
50
0
Percent
0:00:00
0:10:00
0:20:00
0:30:00
0:40:00
0:50:00
1:00:00
1:10:00
1:20:00
1:30:00
1:40:00
1:50:00
2:00:00
2:10:00
2:20:00
2:30:00
2:40:00
2:50:00
3:00:00
3:10:00
3:20:00
Test Elapsed Time
(hrs/min/sec)
The 20u & over efficiency appears to fluctuate greatly due to the low concentration level of those particles, thereby influencing the calculations.
3u to 4u
5u to 9u
10u to 14u
15u to 19u
20u & over

FIGURE 2A

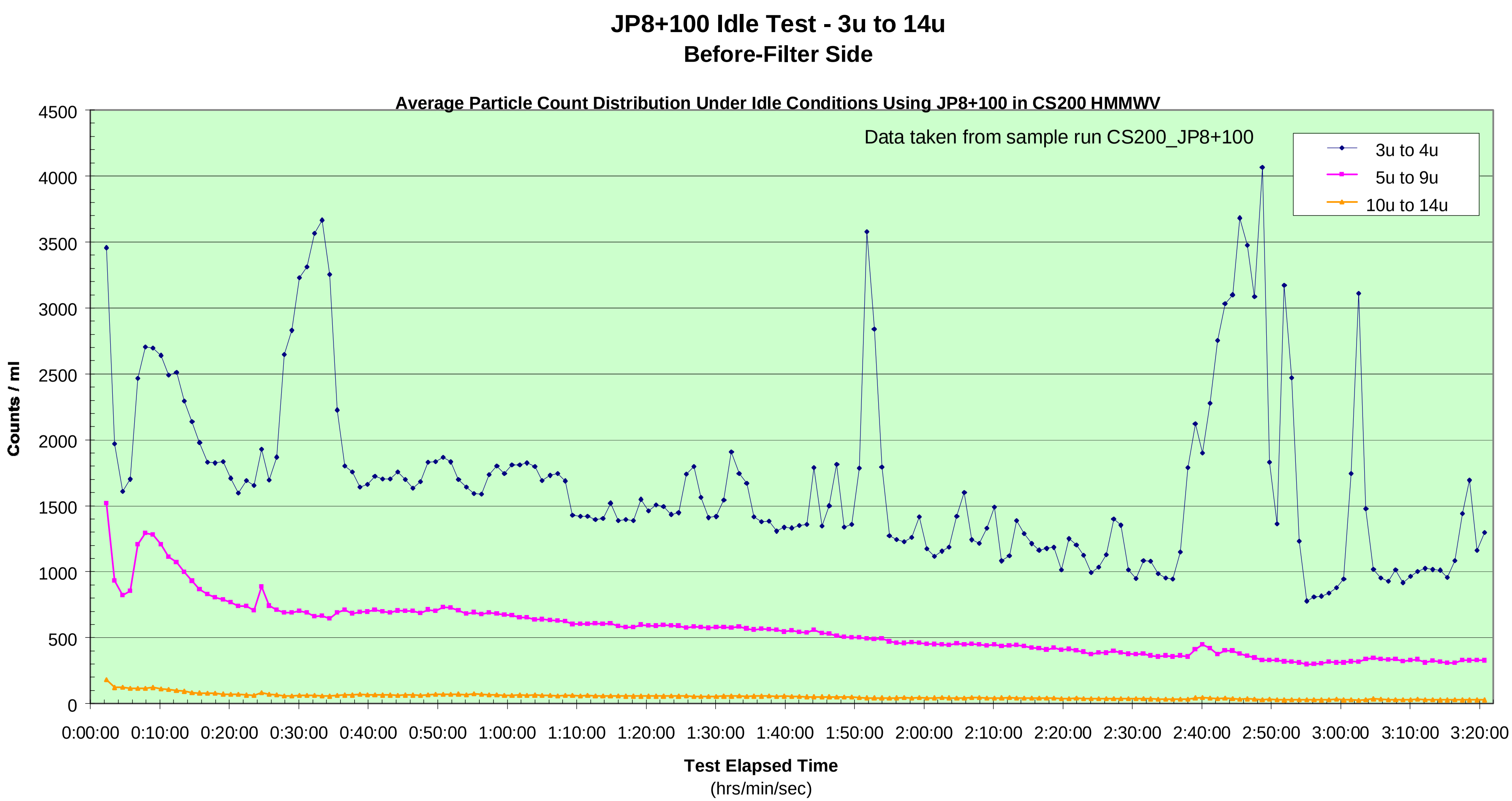

JP8+100 Idle Test - 3u to 14u
Before-Filter Side
Average Particle Count Distribution Under Idle Conditions Using JP8+100 in CS200 HMMWV
Data taken from sample run CS200_JP8+100
3u to 4u
5u to 9u
10u to 14u
Counts / ml
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0:00:00
0:10:00
0:20:00
0:30:00
0:40:00
0:50:00
1:00:00
1:10:00
1:20:00
1:30:00
1:40:00
1:50:00
2:00:00
2:10:00
2:20:00
2:30:00
2:40:00
2:50:00
3:00:00
3:10:00
3:20:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 2B

JP8+100 Idle Test - 10u & over
Before-Filter Side

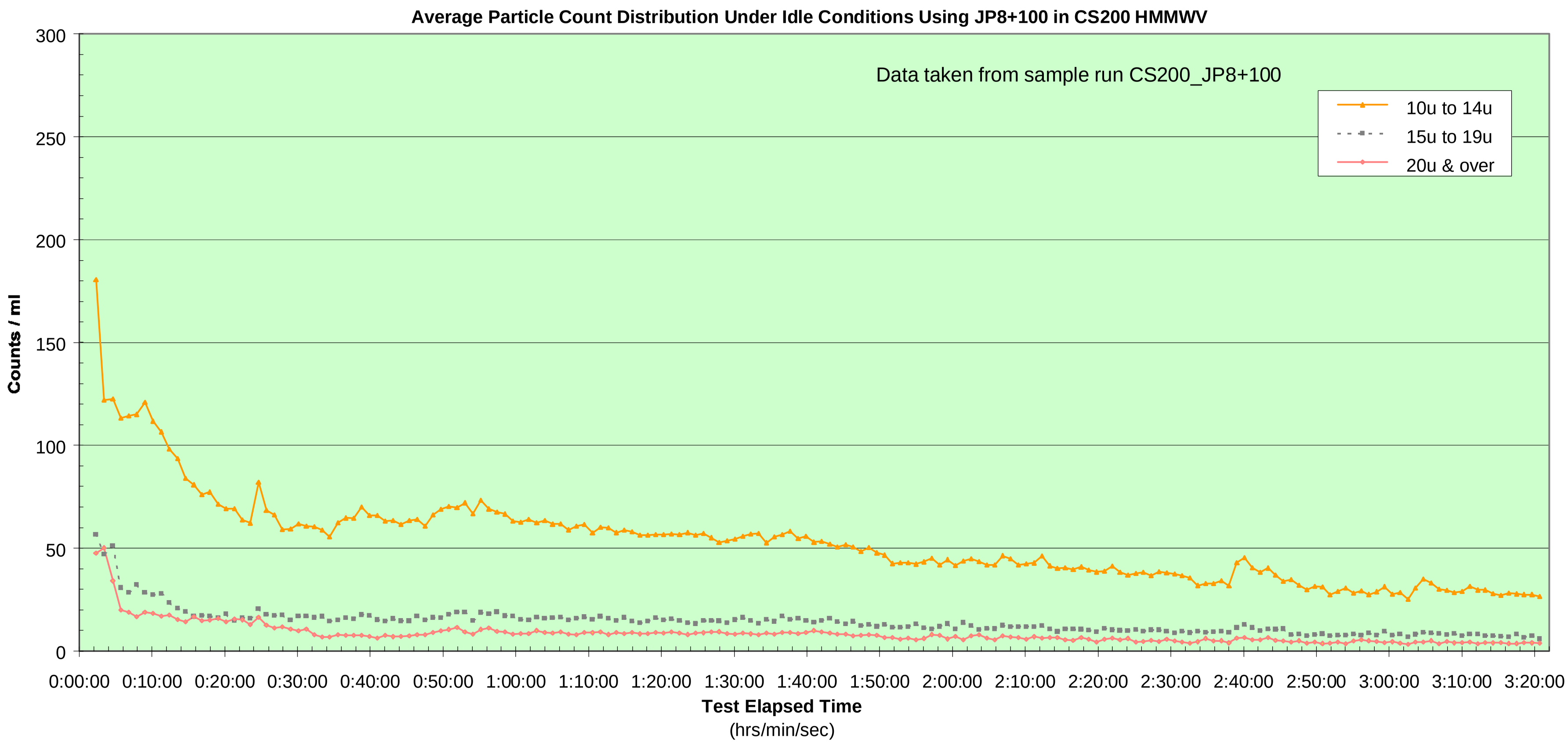


FIGURE 2C

JP8+100 Idle Test - 3u to 14u
After-Filter Side

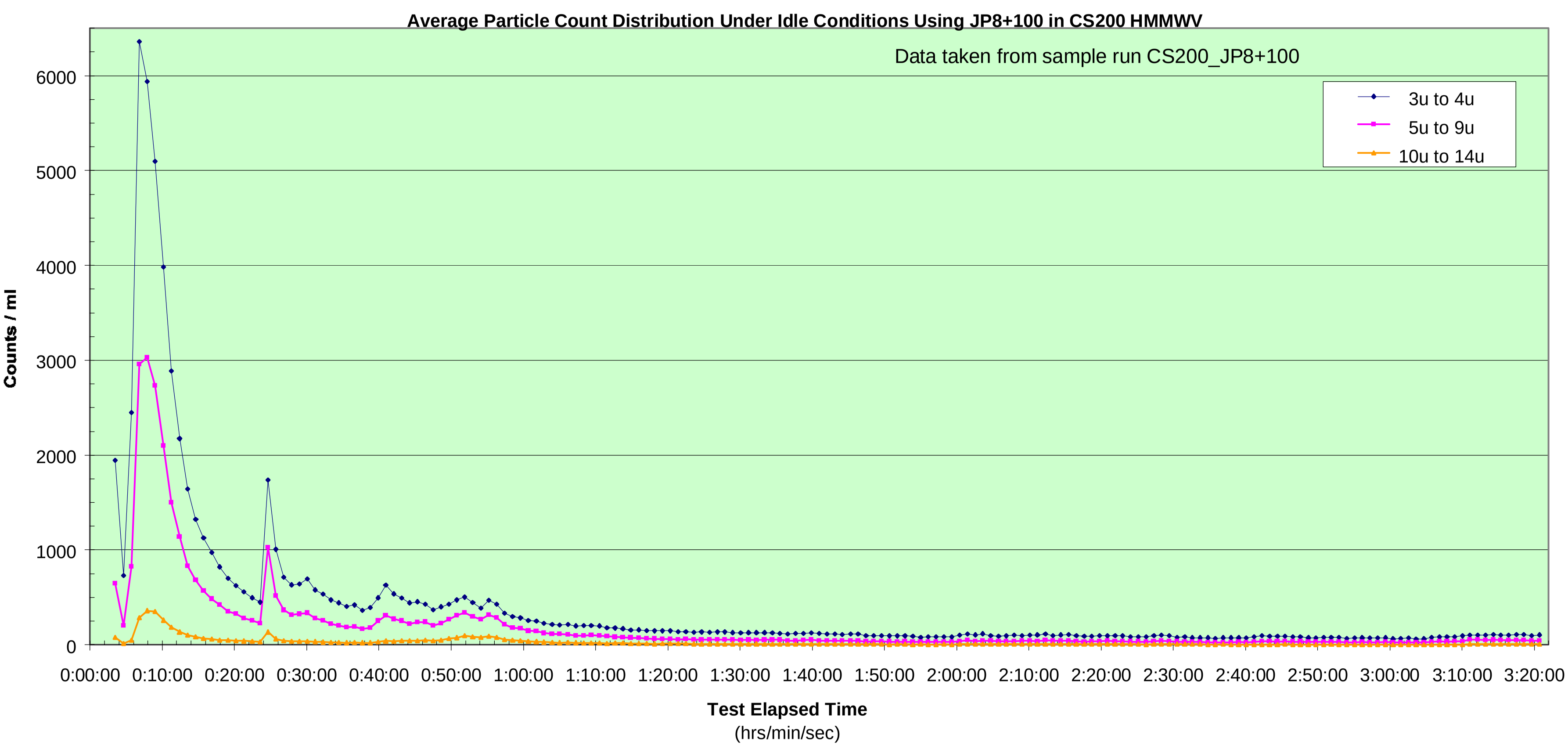


FIGURE 2D

JP8+100 Idle Test - 3u to 14u (detail)
After-Filter Side - before 1:30:00

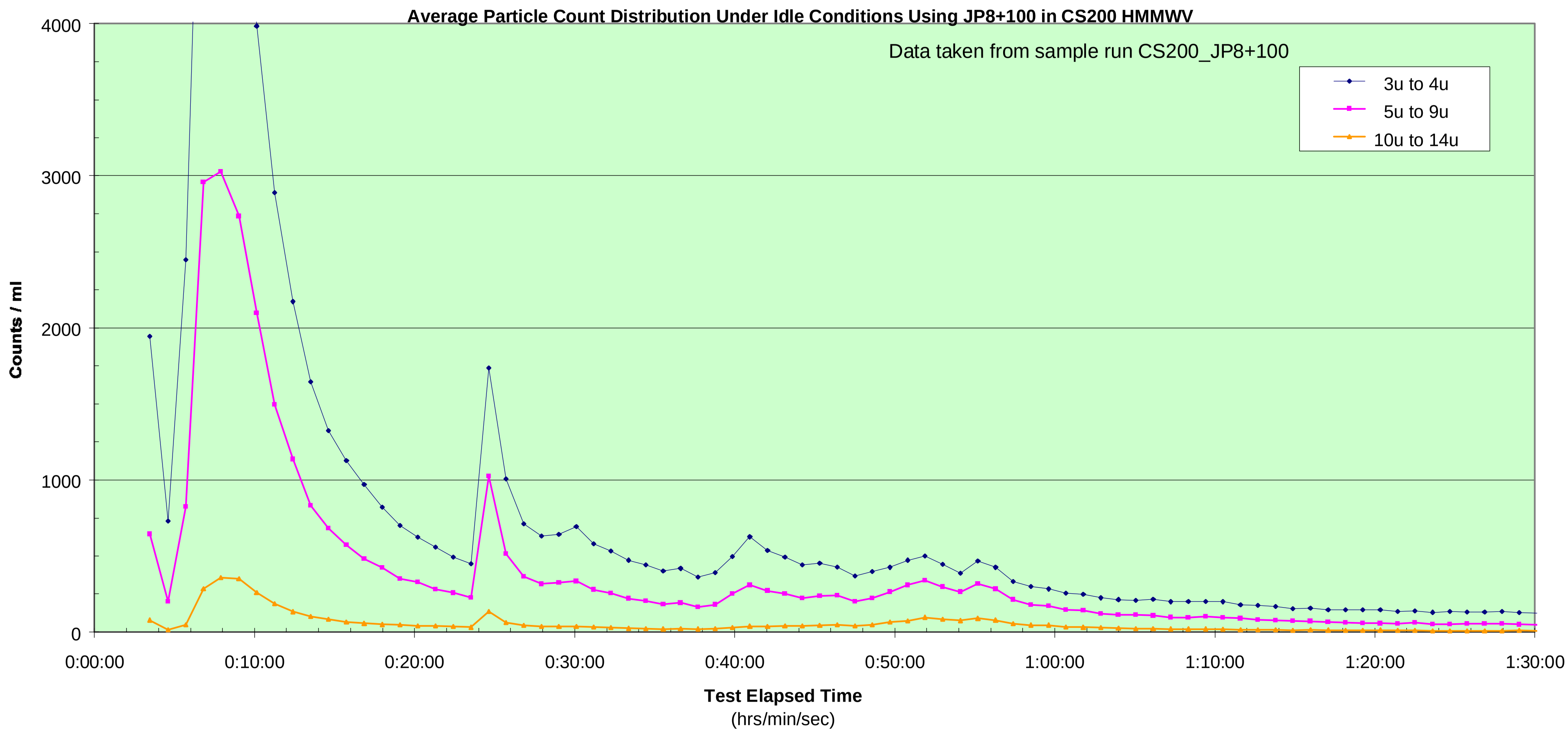


FIGURE 2E

JP8+100 Idle Test - 3u to 14u (detail)
After-Filter Side - after 0:30:00

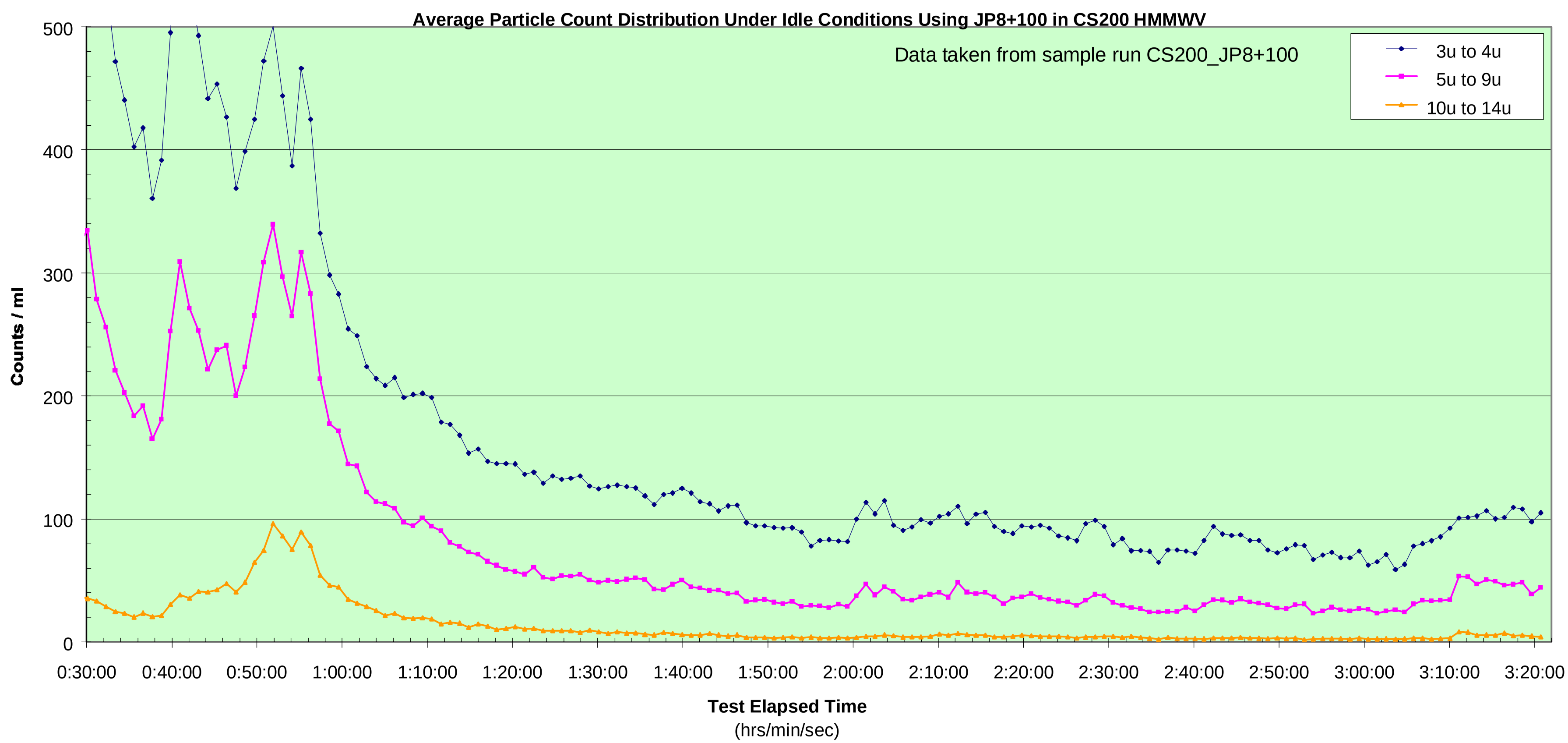


FIGURE 2F

JP8+100 Idle Test - 10u & over
After-Filter Side

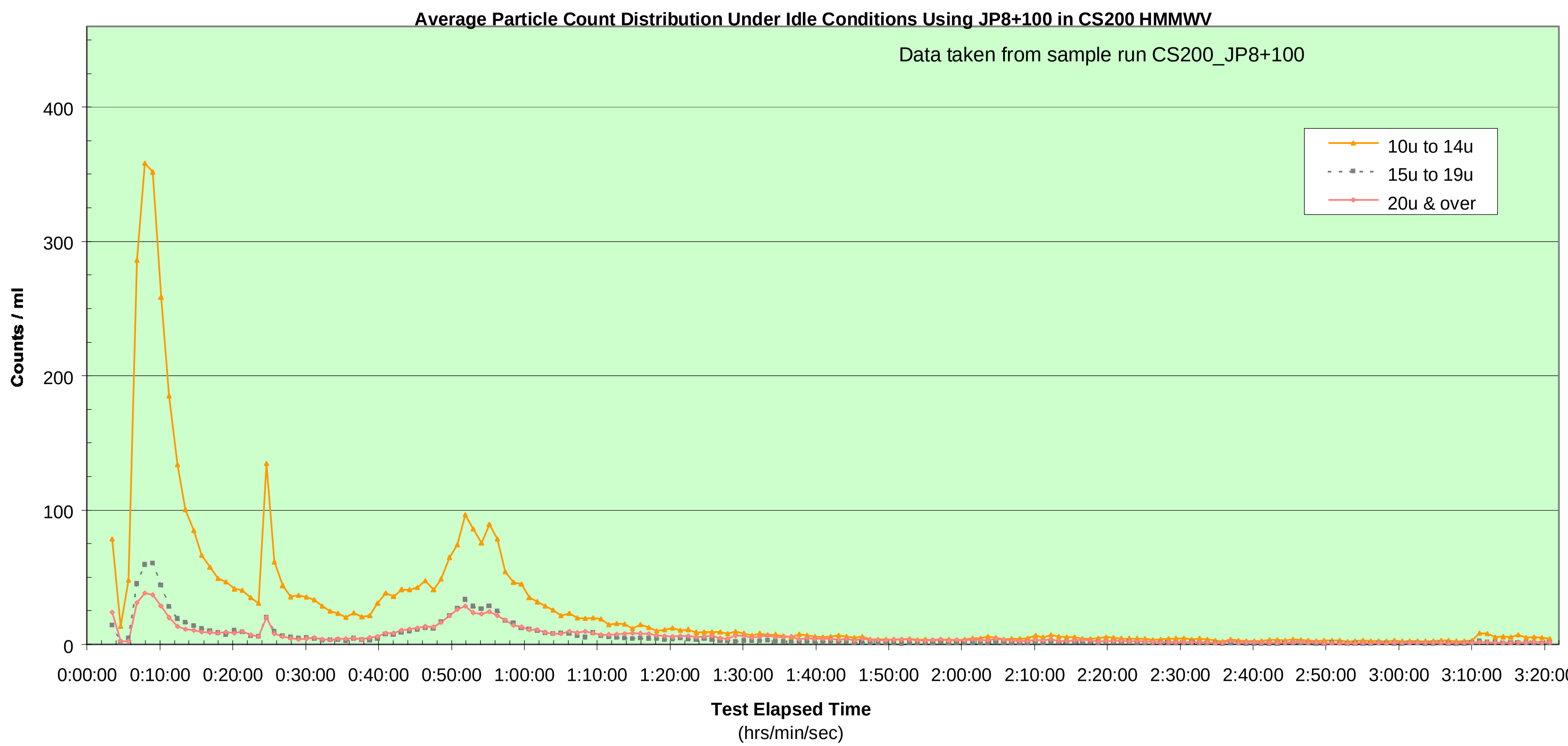


FIGURE 2G

JP8+100 Idle Test - 10u & over (detail)
After-Filter Side - before 1:30:00

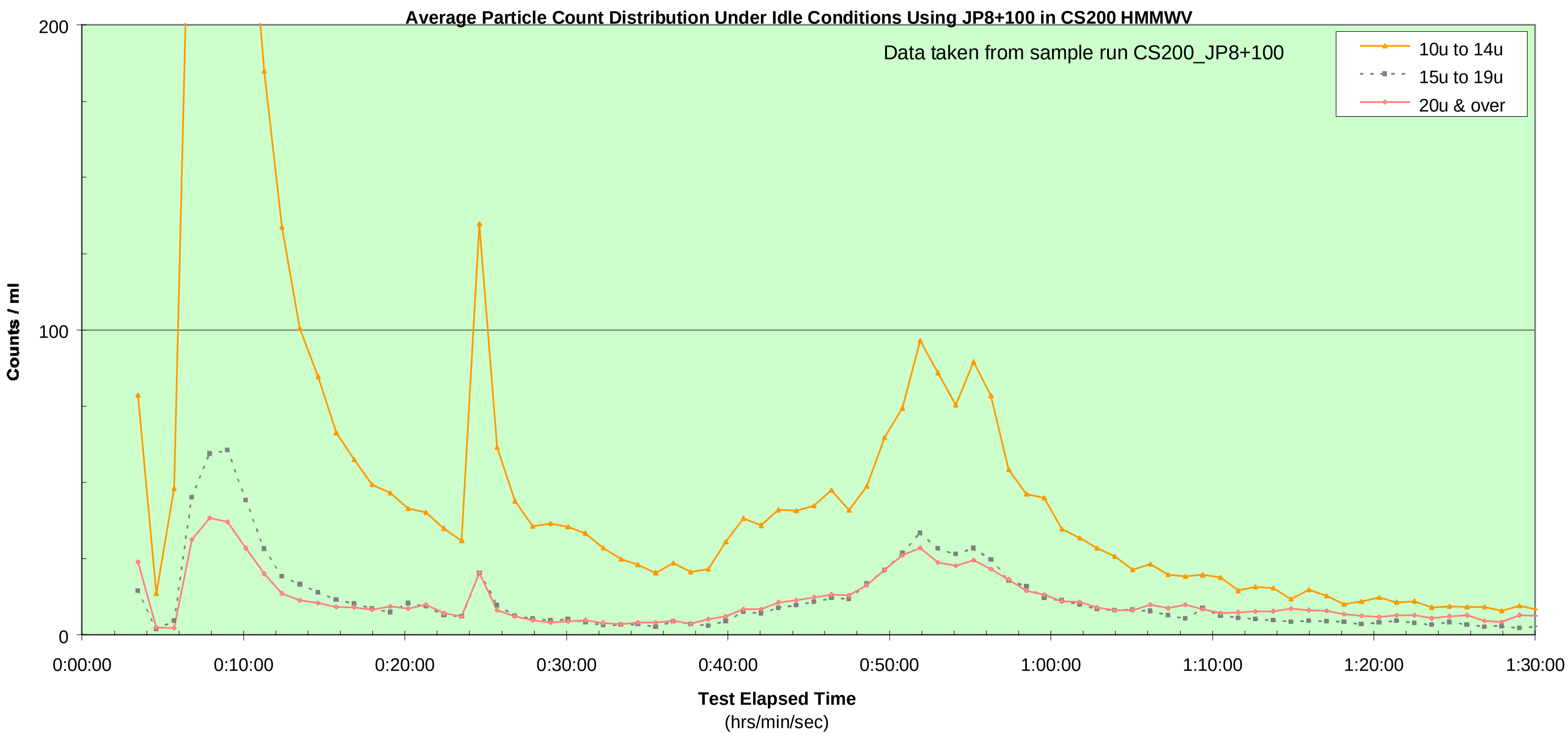


FIGURE 2H

JP8+100 Idle Test - 10u & over (detail)
After-Filter Side - after 1:30:00

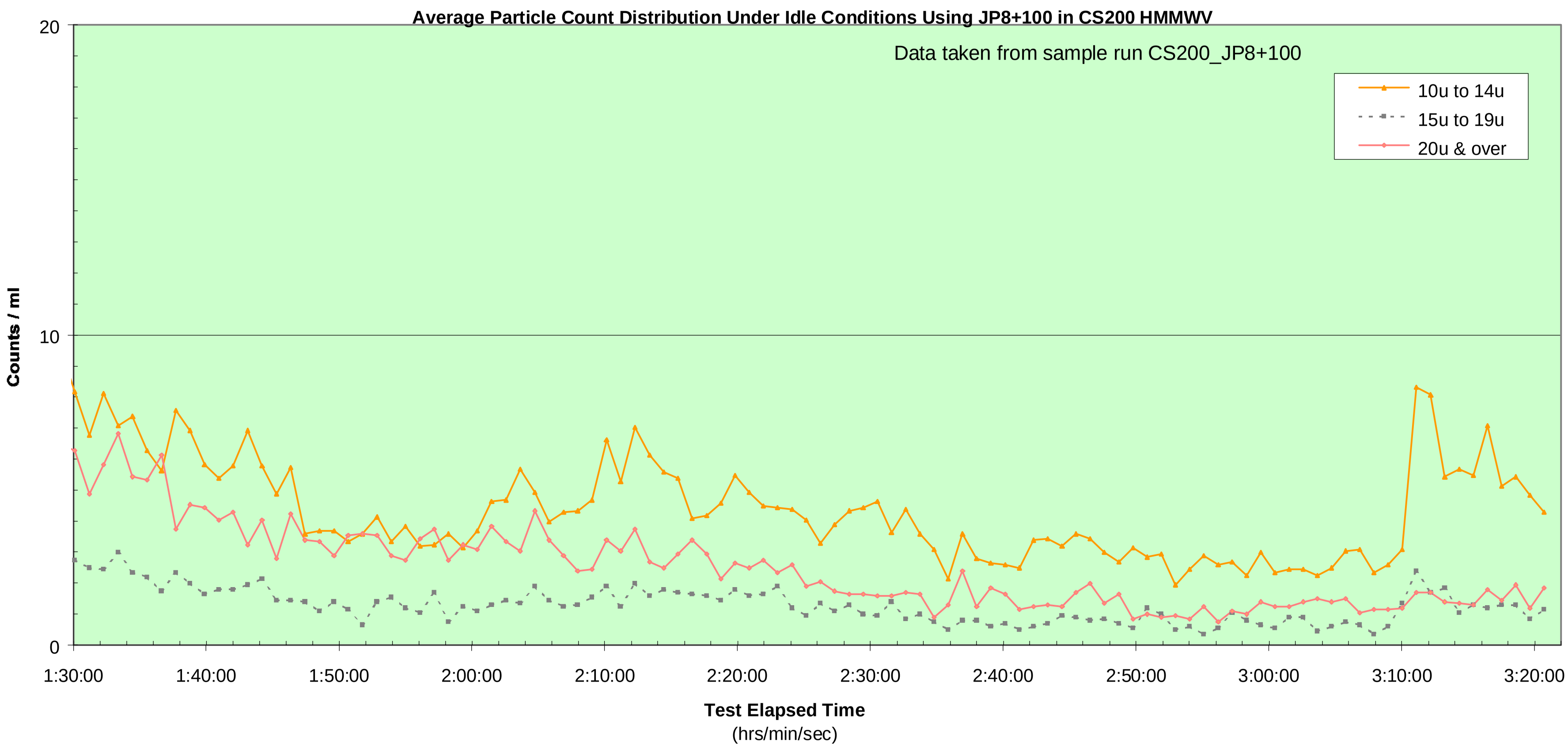


FIGURE 2I

Filtration Efficiency - JP8+100 Idle Test
Based on Particle Size Ranges, CS200 HMMWV

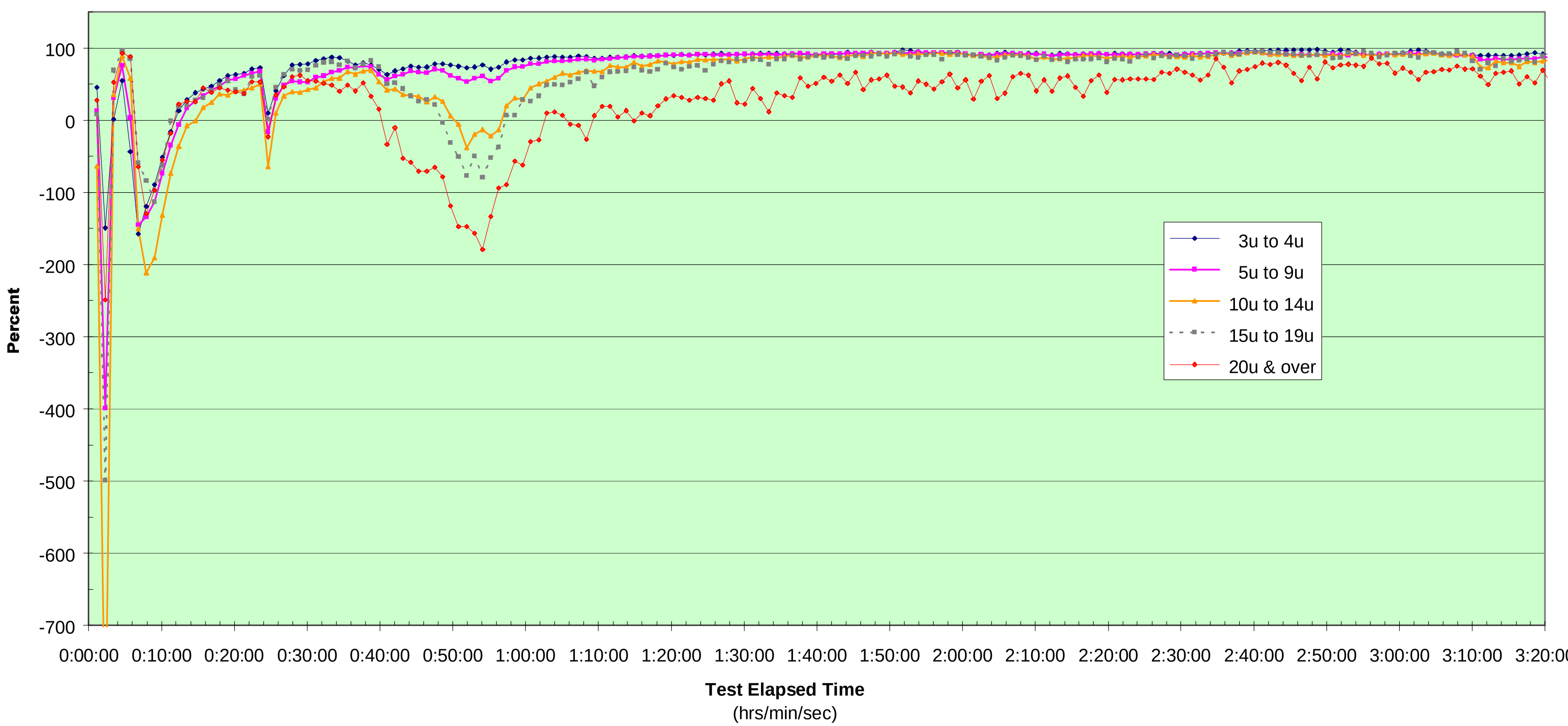


FIGURE 2J

Filtration Efficiency - JP8+100 Idle Test (detail)
Based on Particle Size Ranges, CS200 HMMWV

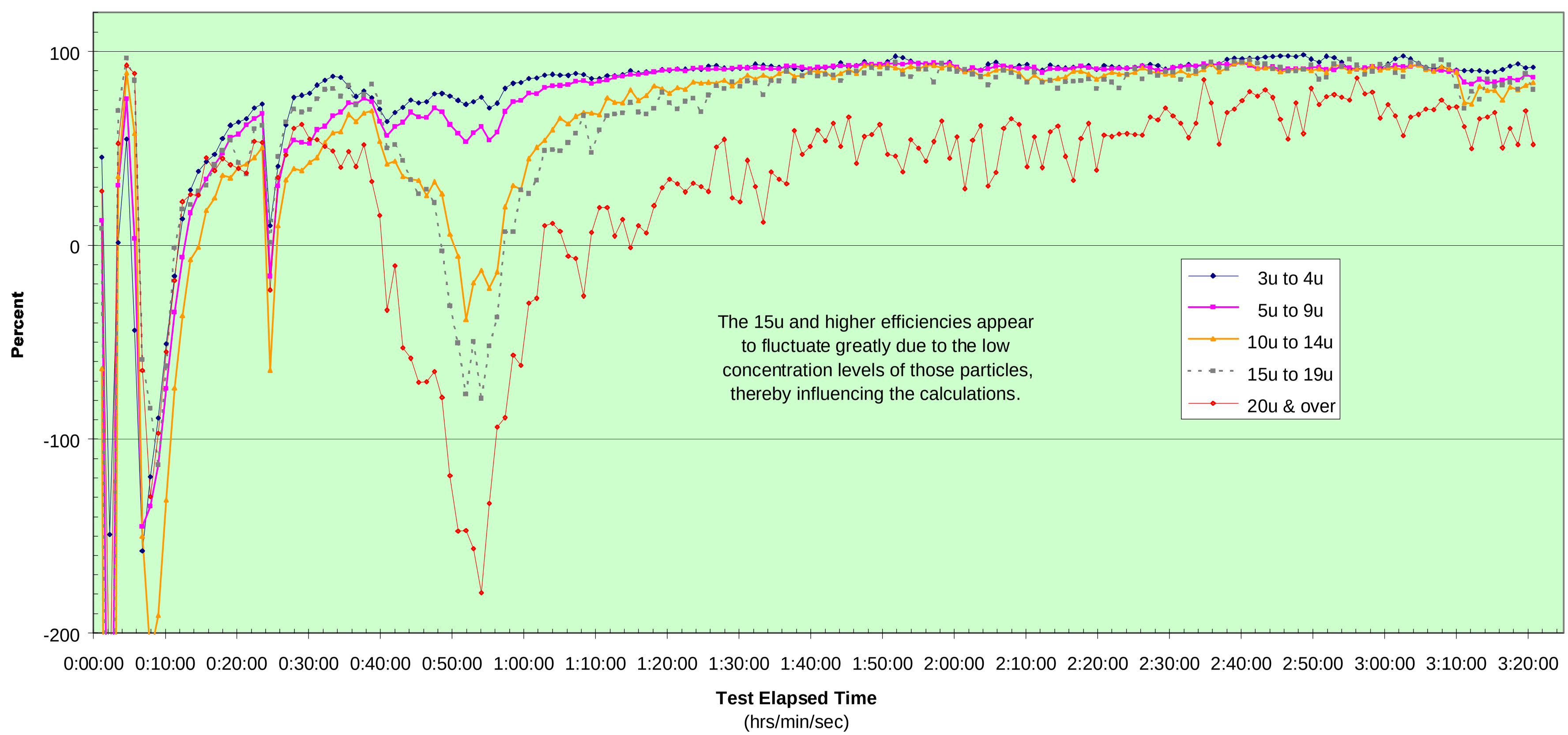


FIGURE 3A

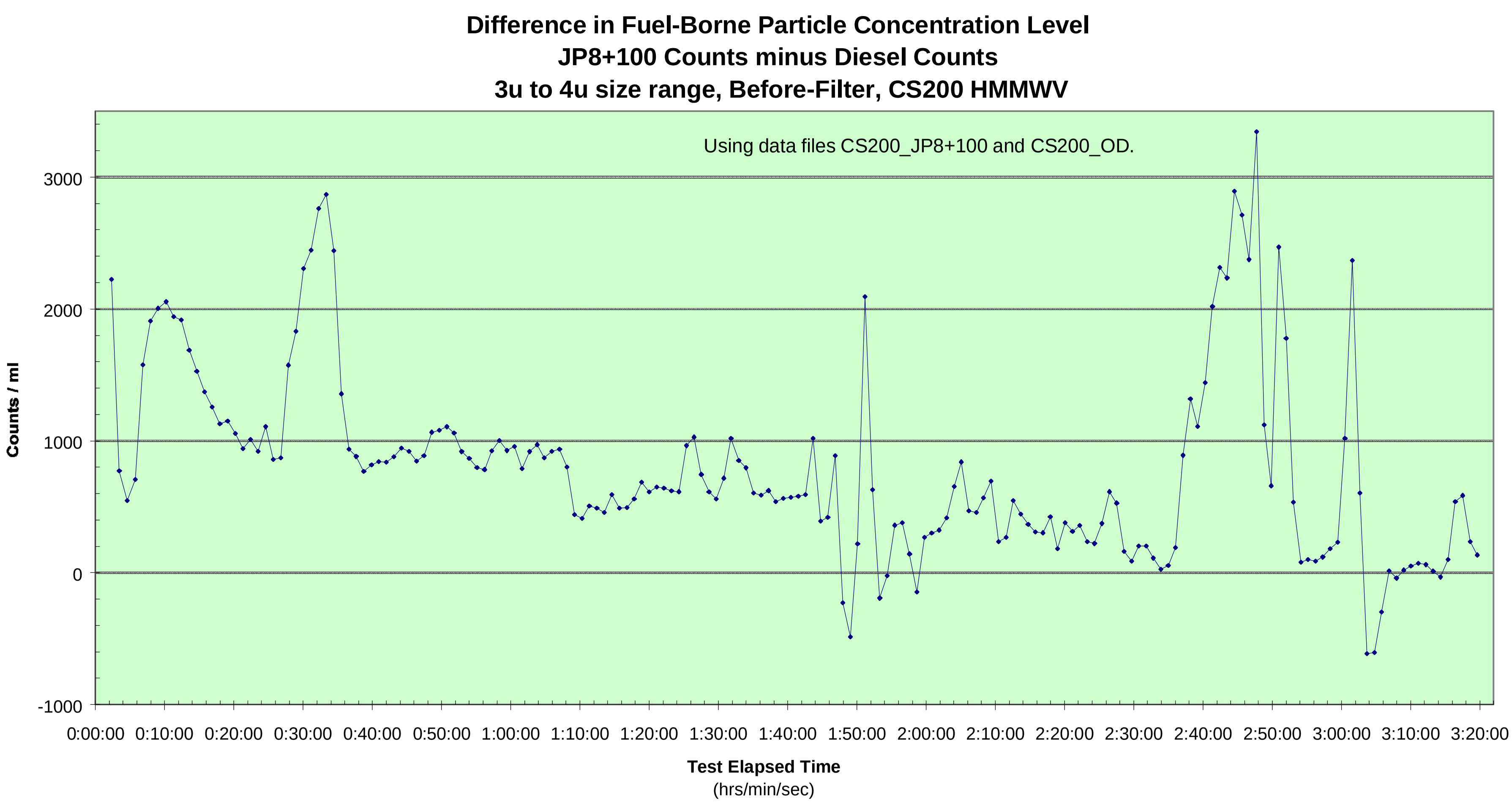
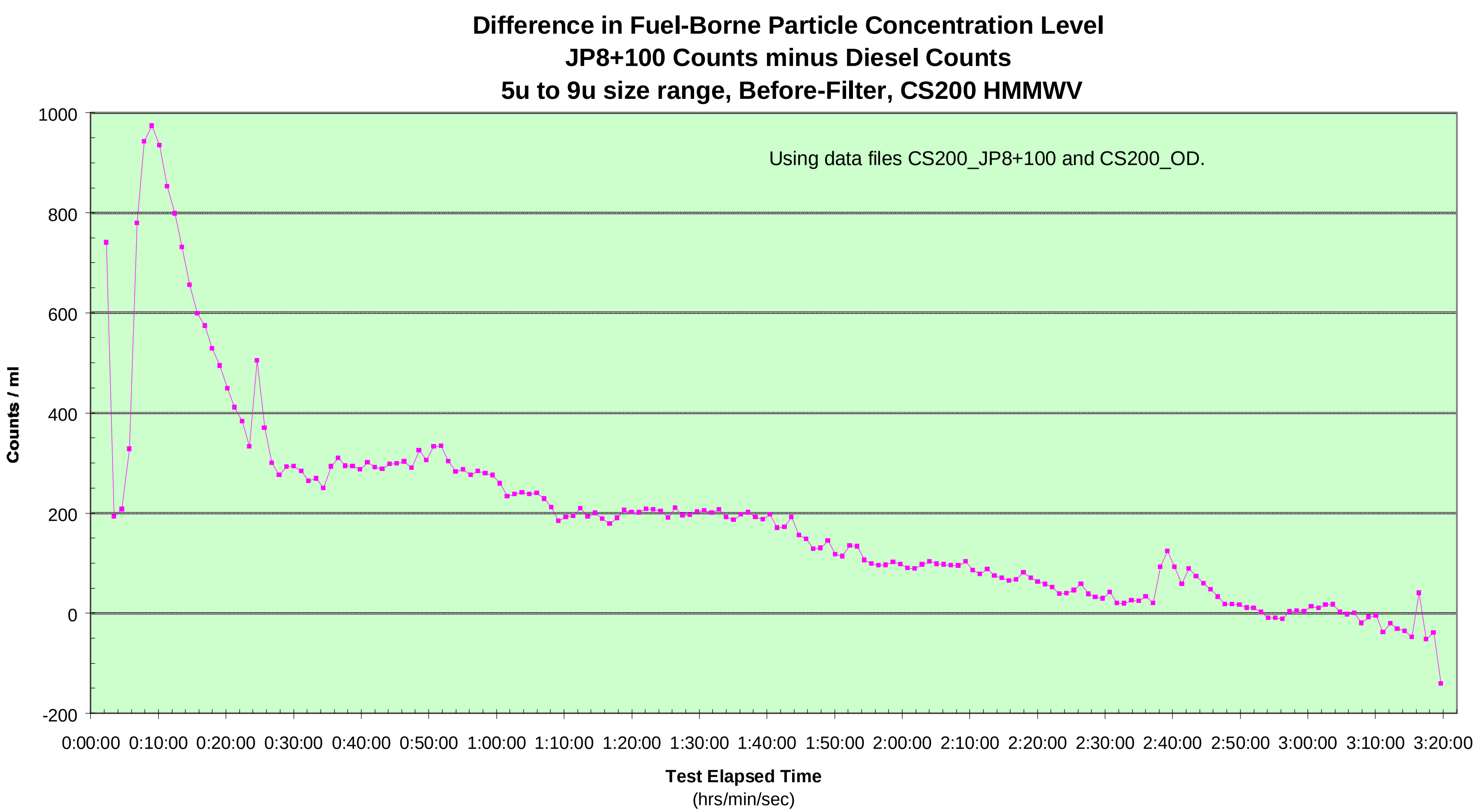

Difference in Fuel-Borne Particle Concentration Level
JP8+100 Counts minus Diesel Counts
3u to 4u size range, Before-Filter, CS200 HMMWV
Using data files CS200_JP8+100 and CS200_OD.
Counts / ml
3000
2000
1000
0
-1000
0:00:00 0:10:00 0:20:00 0:30:00 0:40:00 0:50:00 1:00:00 1:10:00 1:20:00 1:30:00 1:40:00 1:50:00 2:00:00 2:10:00 2:20:00 2:30:00 2:40:00 2:50:00 3:00:00 3:10:00 3:20:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 3B



Difference in Fuel-Borne Particle Concentration Level
JP8+100 Counts minus Diesel Counts
5u to 9u size range, Before-Filter, CS200 HMMWV
Using data files CS200_JP8+100 and CS200_OD.
Counts / ml
1000
800
600
400
200
0
-200
0:00:00
0:10:00
0:20:00
0:30:00
0:40:00
0:50:00
1:00:00
1:10:00
1:20:00
1:30:00
1:40:00
1:50:00
2:00:00
2:10:00
2:20:00
2:30:00
2:40:00
2:50:00
3:00:00
3:10:00
3:20:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 3C

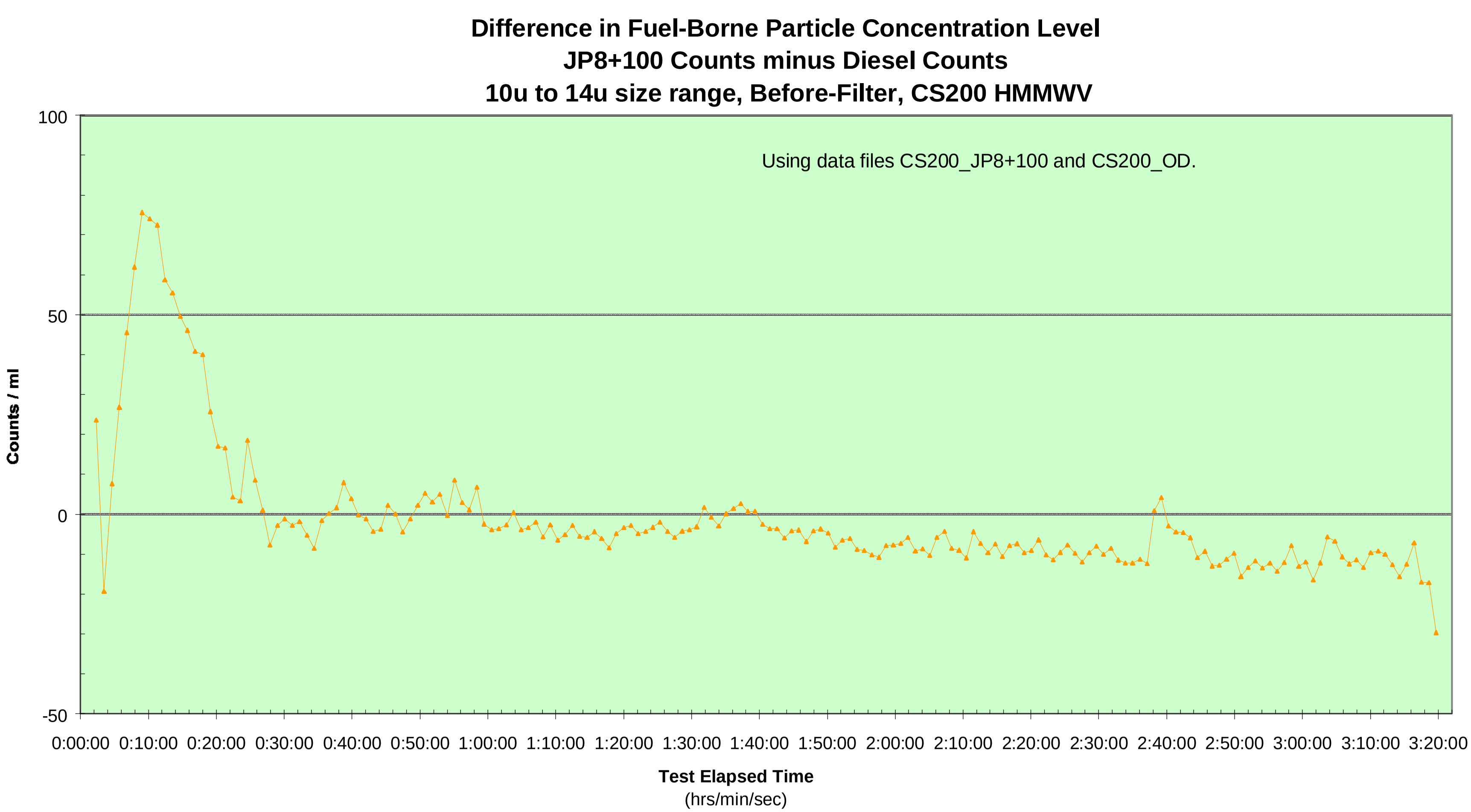

Difference in Fuel-Borne Particle Concentration Level
JP8+100 Counts minus Diesel Counts
10u to 14u size range, Before-Filter, CS200 HMMWV
Using data files CS200_JP8+100 and CS200_OD.
Counts / ml
100
50
0
-50
0:00:00
0:10:00
0:20:00
0:30:00
0:40:00
0:50:00
1:00:00
1:10:00
1:20:00
1:30:00
1:40:00
1:50:00
2:00:00
2:10:00
2:20:00
2:30:00
2:40:00
2:50:00
3:00:00
3:10:00
3:20:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 3D

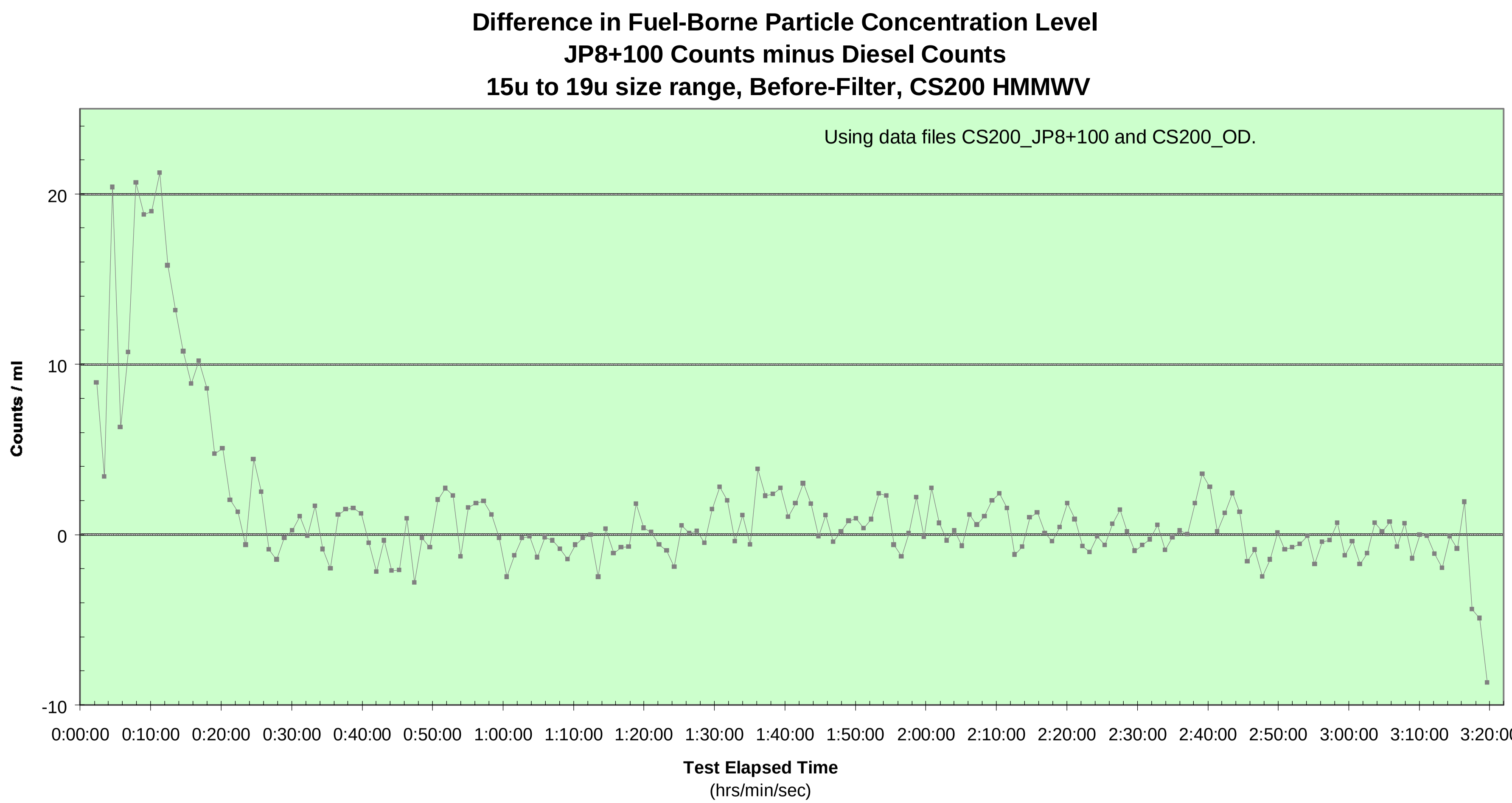

Difference in Fuel-Borne Particle Concentration Level
JP8+100 Counts minus Diesel Counts
15u to 19u size range, Before-Filter, CS200 HMMWV
Using data files CS200_JP8+100 and CS200_OD.
Counts / ml
20
10
0
-10
0:00:00
0:10:00
0:20:00
0:30:00
0:40:00
0:50:00
1:00:00
1:10:00
1:20:00
1:30:00
1:40:00
1:50:00
2:00:00
2:10:00
2:20:00
2:30:00
2:40:00
2:50:00
3:00:00
3:10:00
3:20:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 3E

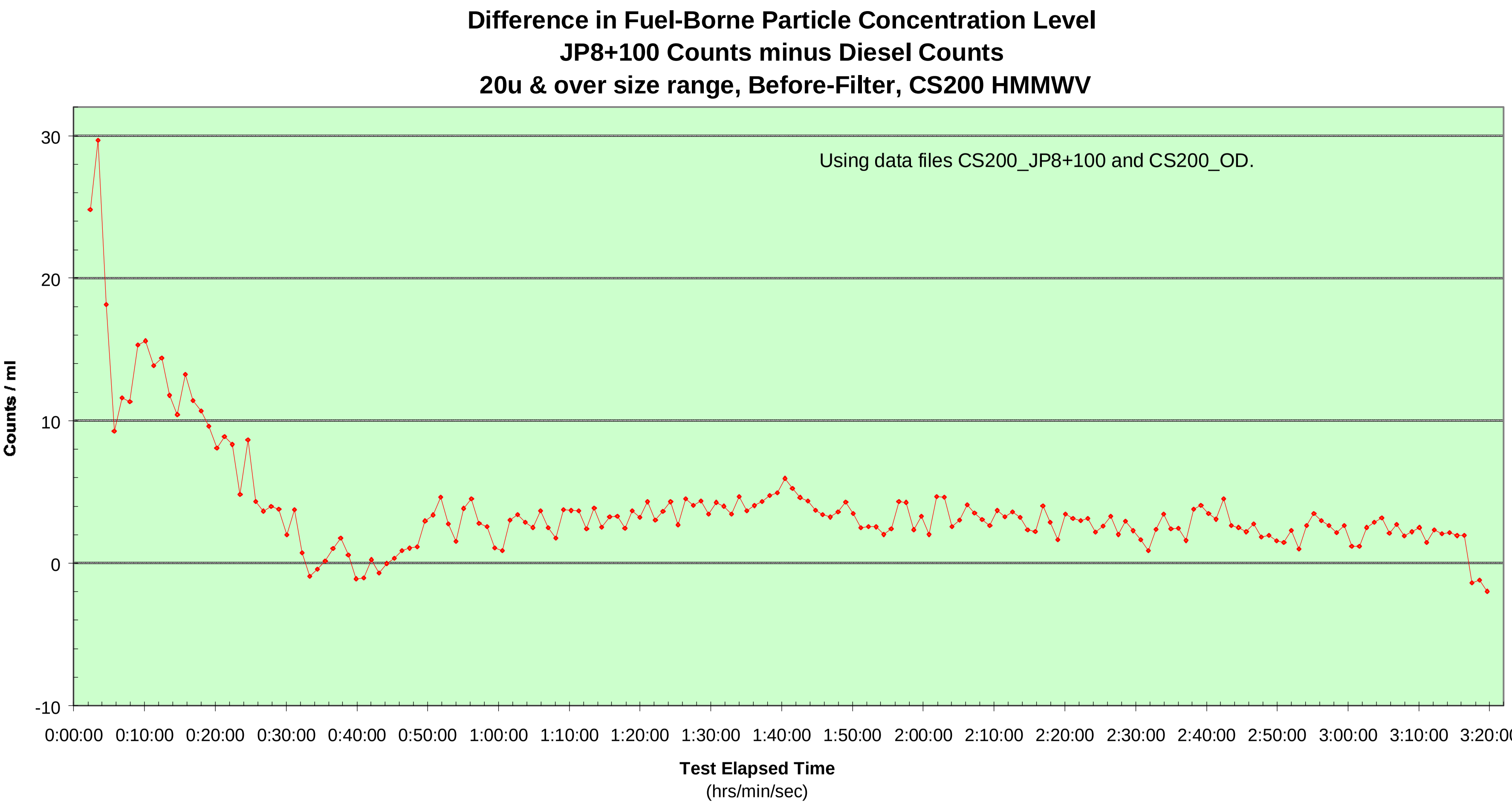

Difference in Fuel-Borne Particle Concentration Level
JP8+100 Counts minus Diesel Counts
20u & over size range, Before-Filter, CS200 HMMWV
Using data files CS200_JP8+100 and CS200_OD.
30
20
10
0
-10
Counts / ml
0:00:00
0:10:00
0:20:00
0:30:00
0:40:00
0:50:00
1:00:00
1:10:00
1:20:00
1:30:00
1:40:00
1:50:00
2:00:00
2:10:00
2:20:00
2:30:00
2:40:00
2:50:00
3:00:00
3:10:00
3:20:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 3F

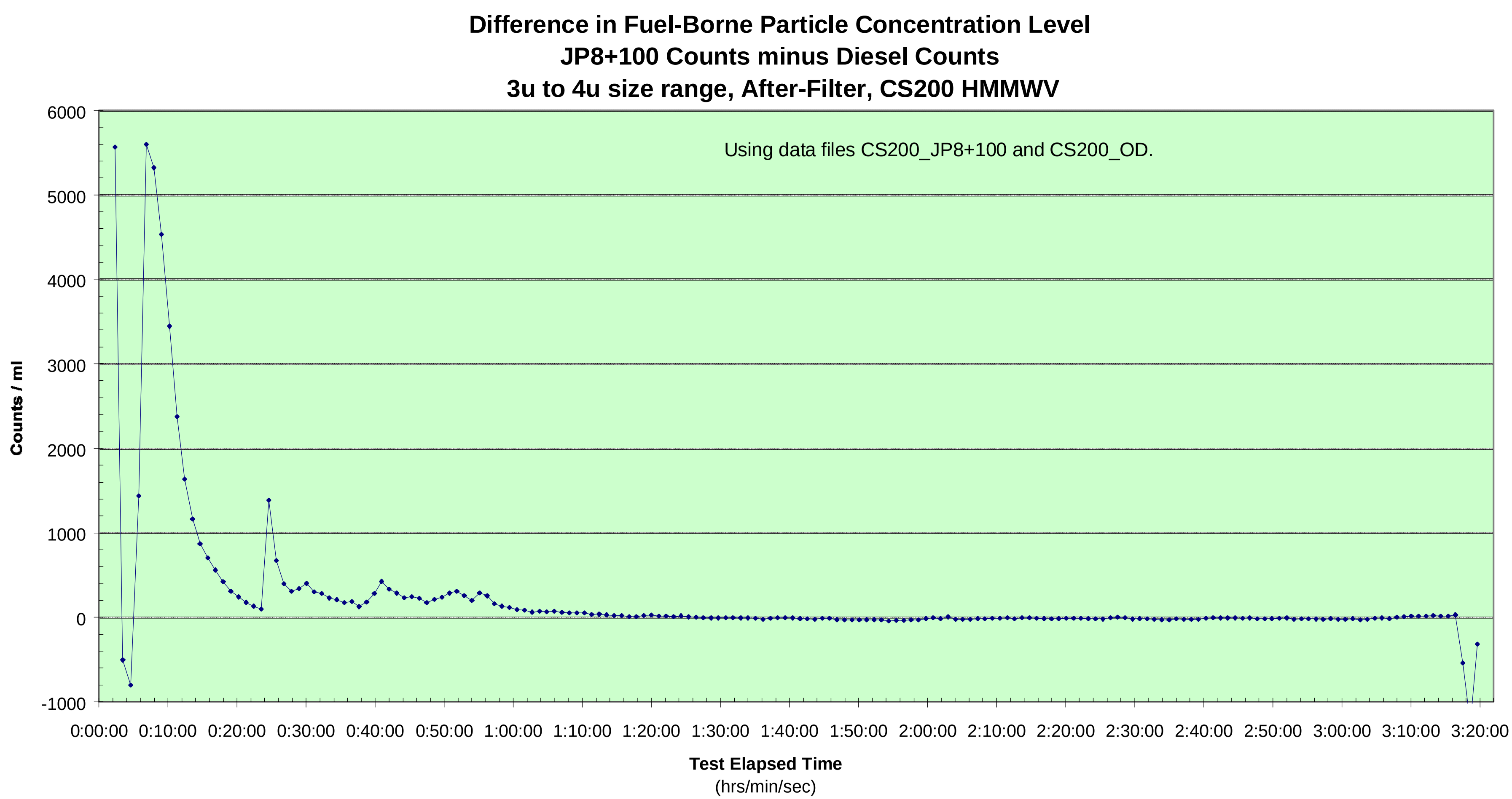

Difference in Fuel-Borne Particle Concentration Level
JP8+100 Counts minus Diesel Counts
3u to 4u size range, After-Filter, CS200 HMMWV
Using data files CS200_JP8+100 and CS200_OD.
Counts / ml
6000
5000
4000
3000
2000
1000
0
-1000
0:00:00
0:10:00
0:20:00
0:30:00
0:40:00
0:50:00
1:00:00
1:10:00
1:20:00
1:30:00
1:40:00
1:50:00
2:00:00
2:10:00
2:20:00
2:30:00
2:40:00
2:50:00
3:00:00
3:10:00
3:20:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 3G

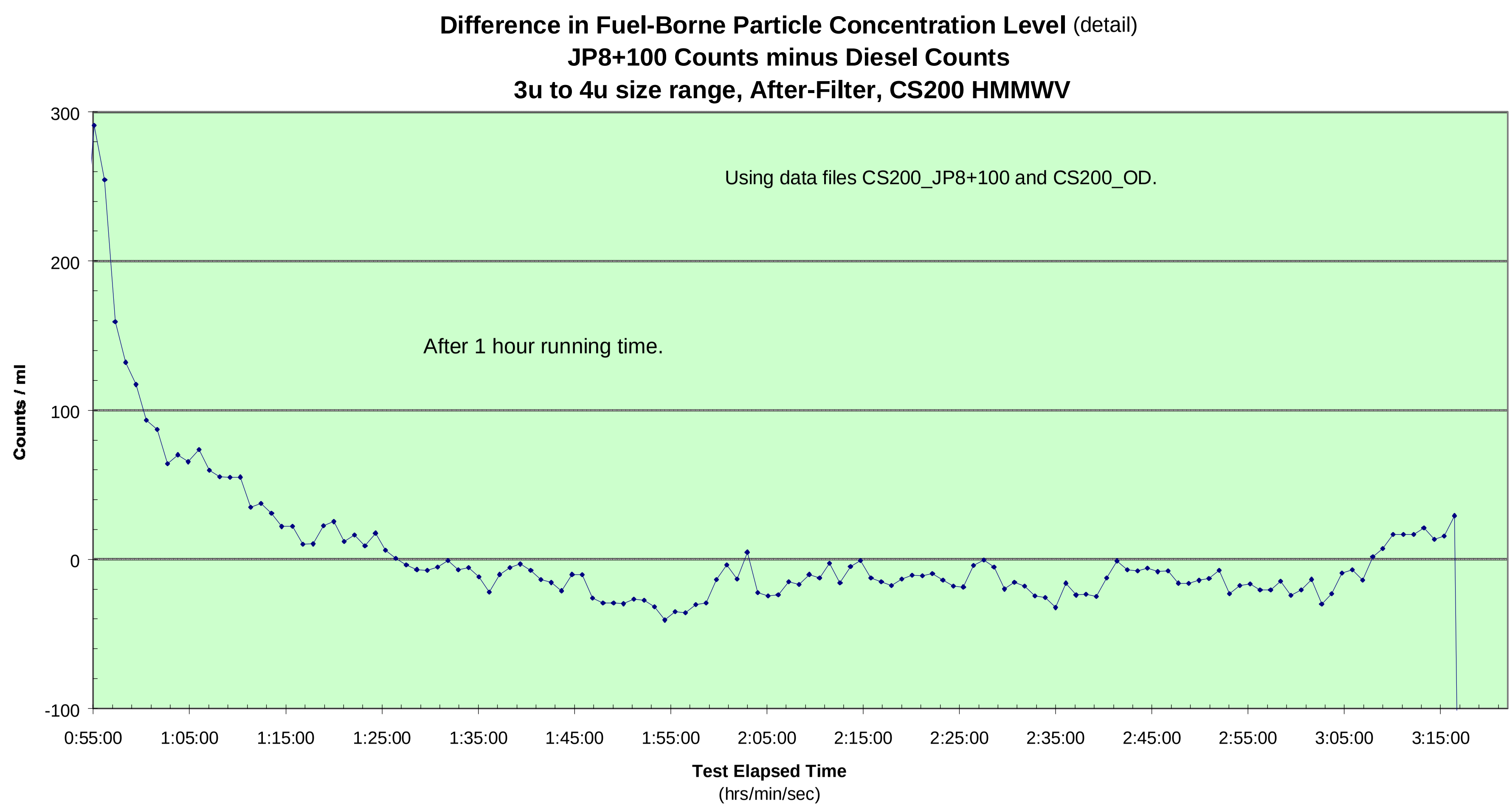
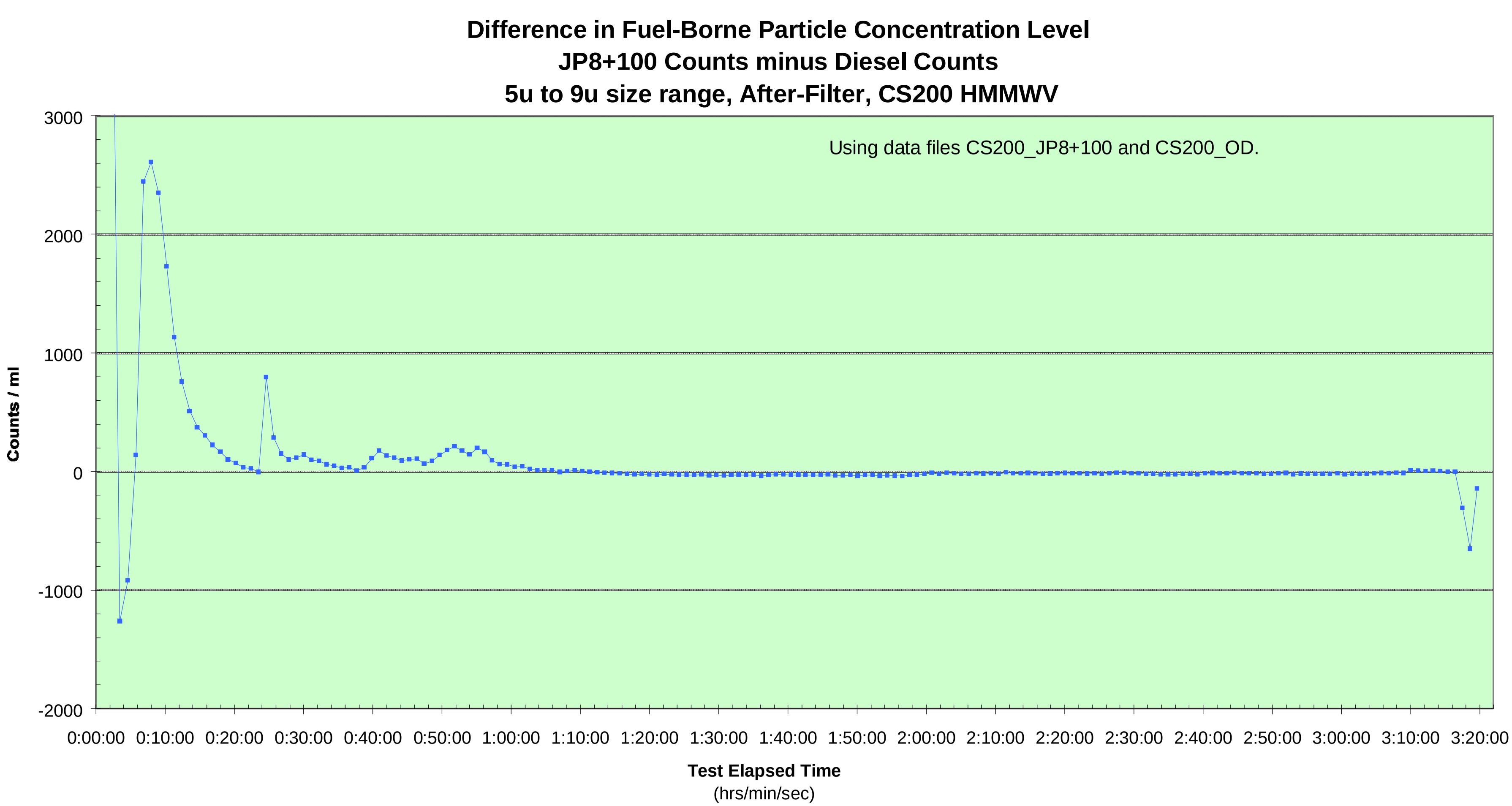

Difference in Fuel-Borne Particle Concentration Level (detail)
JP8+100 Counts minus Diesel Counts
3u to 4u size range, After-Filter, CS200 HMMWV
Using data files CS200_JP8+100 and CS200_OD.
After 1 hour running time.
Counts / ml
300
200
100
0
-100
0:55:00
1:05:00
1:15:00
1:25:00
1:35:00
1:45:00
1:55:00
2:05:00
2:15:00
2:25:00
2:35:00
2:45:00
2:55:00
3:05:00
3:15:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 3H



Difference in Fuel-Borne Particle Concentration Level
JP8+100 Counts minus Diesel Counts
5u to 9u size range, After-Filter, CS200 HMMWV
Using data files CS200_JP8+100 and CS200_OD.
Counts / ml
3000
2000
1000
0
-1000
-2000
0:00:00
0:10:00
0:20:00
0:30:00
0:40:00
0:50:00
1:00:00
1:10:00
1:20:00
1:30:00
1:40:00
1:50:00
2:00:00
2:10:00
2:20:00
2:30:00
2:40:00
2:50:00
3:00:00
3:10:00
3:20:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 3I

Difference in Fuel-Borne Particle Concentration Level (detail)
JP8+100 Counts minus Diesel Counts
5u to 9u size range, After-Filter, CS200 HMMWV

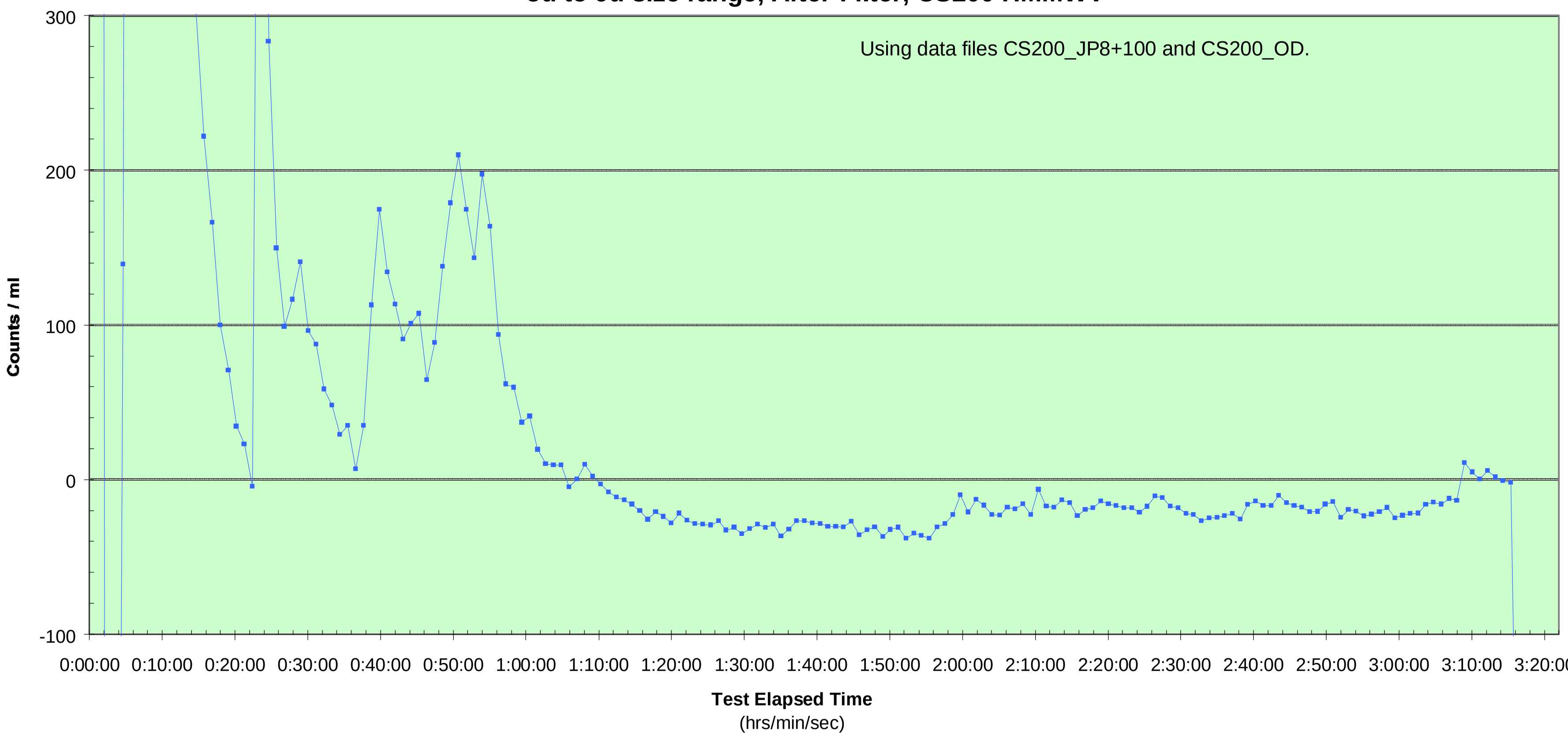


FIGURE 3J

Difference in Fuel-Borne Particle Concentration Level
JP8+100 Counts minus Diesel Counts
10u to 14u size range, After-Filter, CS200 HMMWV

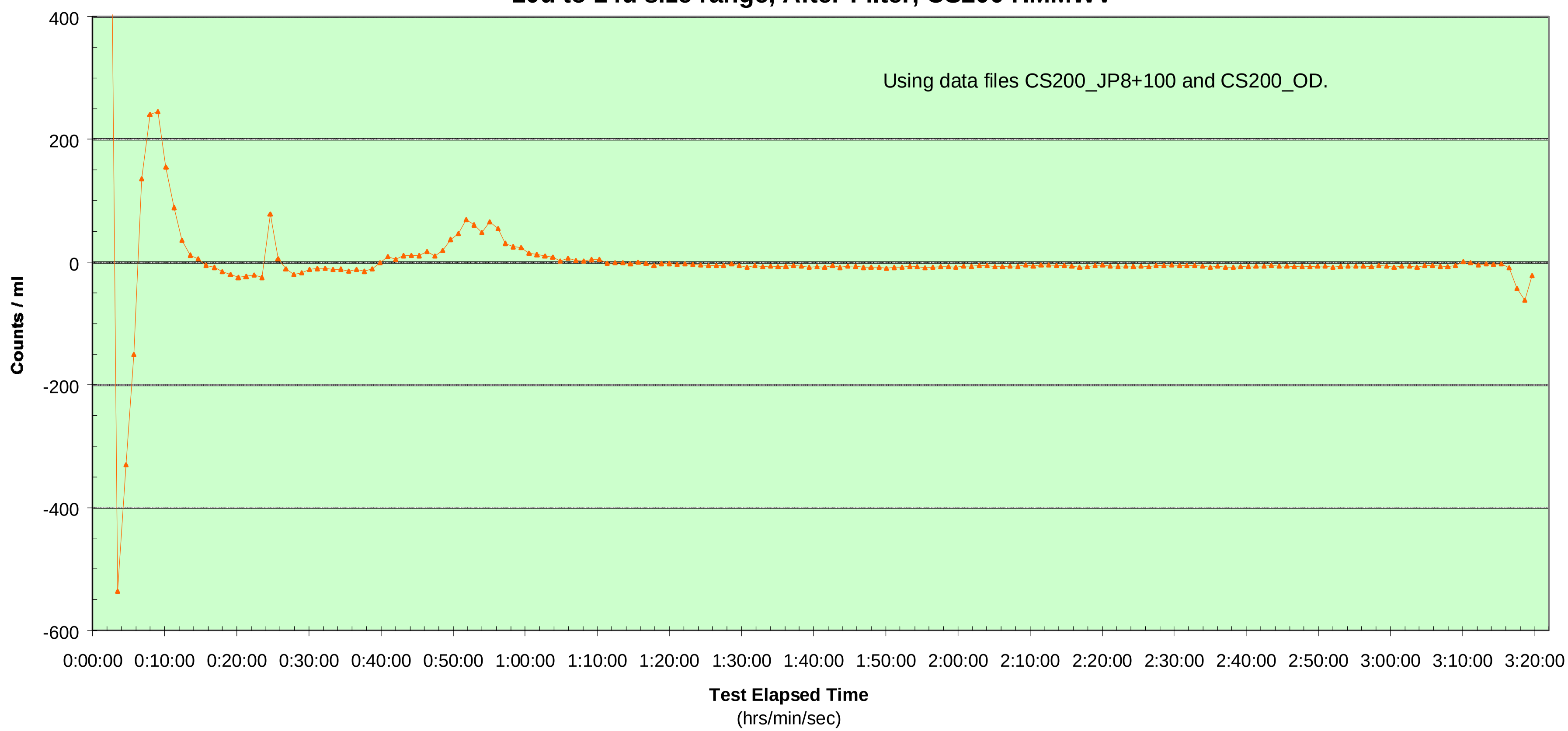


FIGURE 3K

Difference in Fuel-Borne Particle Concentration Level (detail)
JP8+100 Counts minus Diesel Counts
10u to 14u size range, After-Filter, CS200 HMMWV

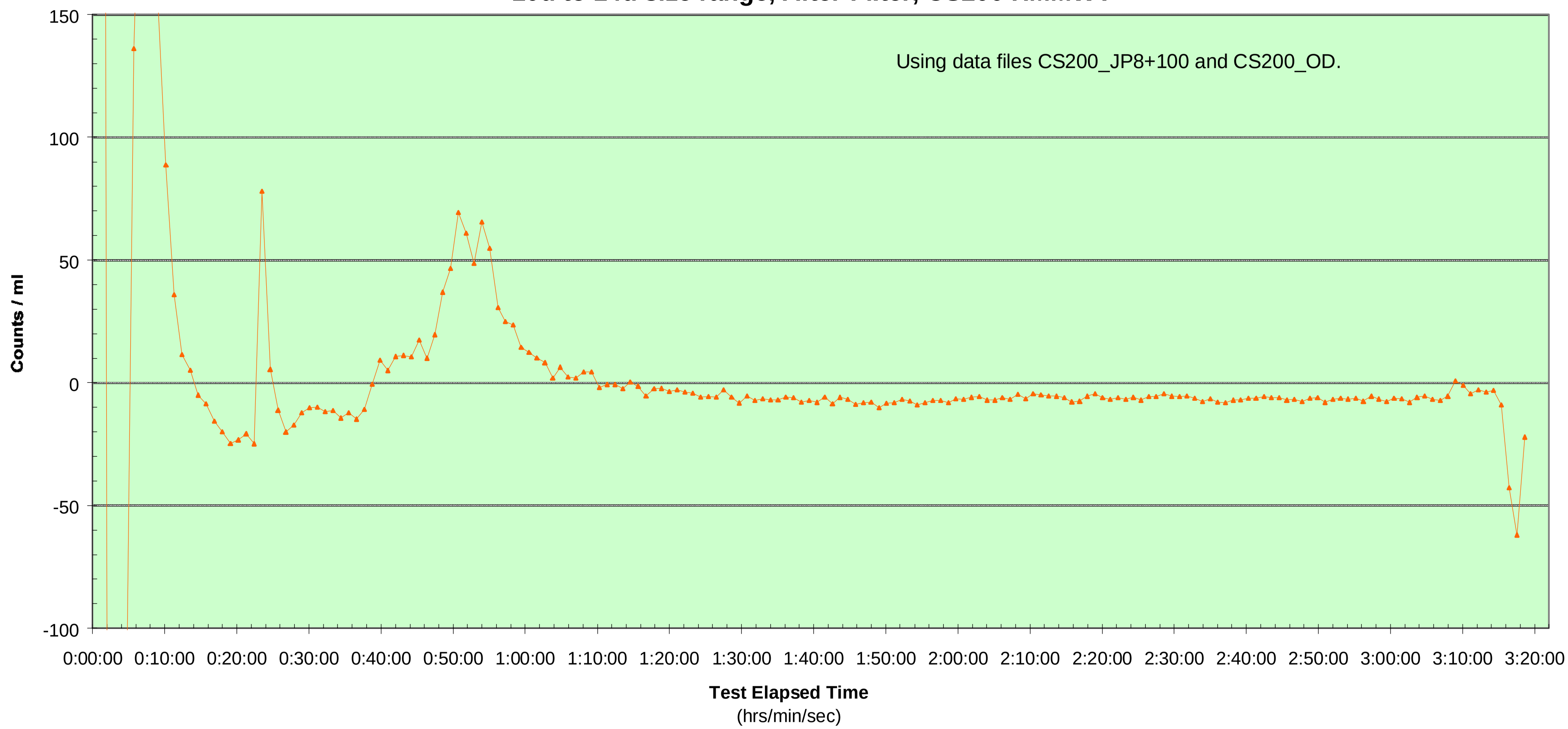


FIGURE 3L

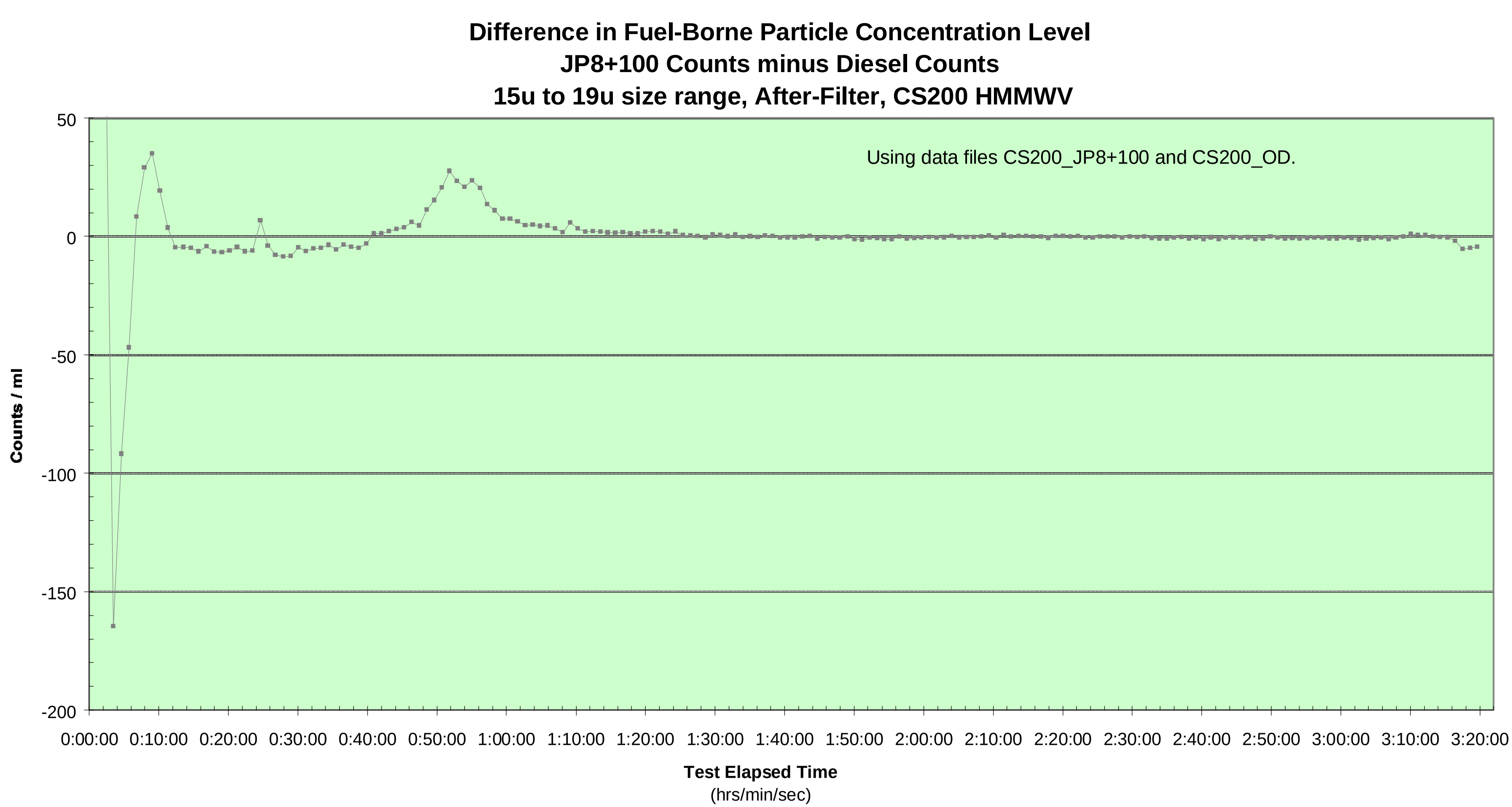

Difference in Fuel-Borne Particle Concentration Level
JP8+100 Counts minus Diesel Counts
15u to 19u size range, After-Filter, CS200 HMMWV
Using data files CS200_JP8+100 and CS200_OD.
Counts / ml
50
0
-50
-100
-150
-200
0:00:00
0:10:00
0:20:00
0:30:00
0:40:00
0:50:00
1:00:00
1:10:00
1:20:00
1:30:00
1:40:00
1:50:00
2:00:00
2:10:00
2:20:00
2:30:00
2:40:00
2:50:00
3:00:00
3:10:00
3:20:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 3M

Difference in Fuel-Borne Particle Concentration Level (detail)
JP8+100 Counts minus Diesel Counts
15u to 19u size range, After-Filter, CS200 HMMWV

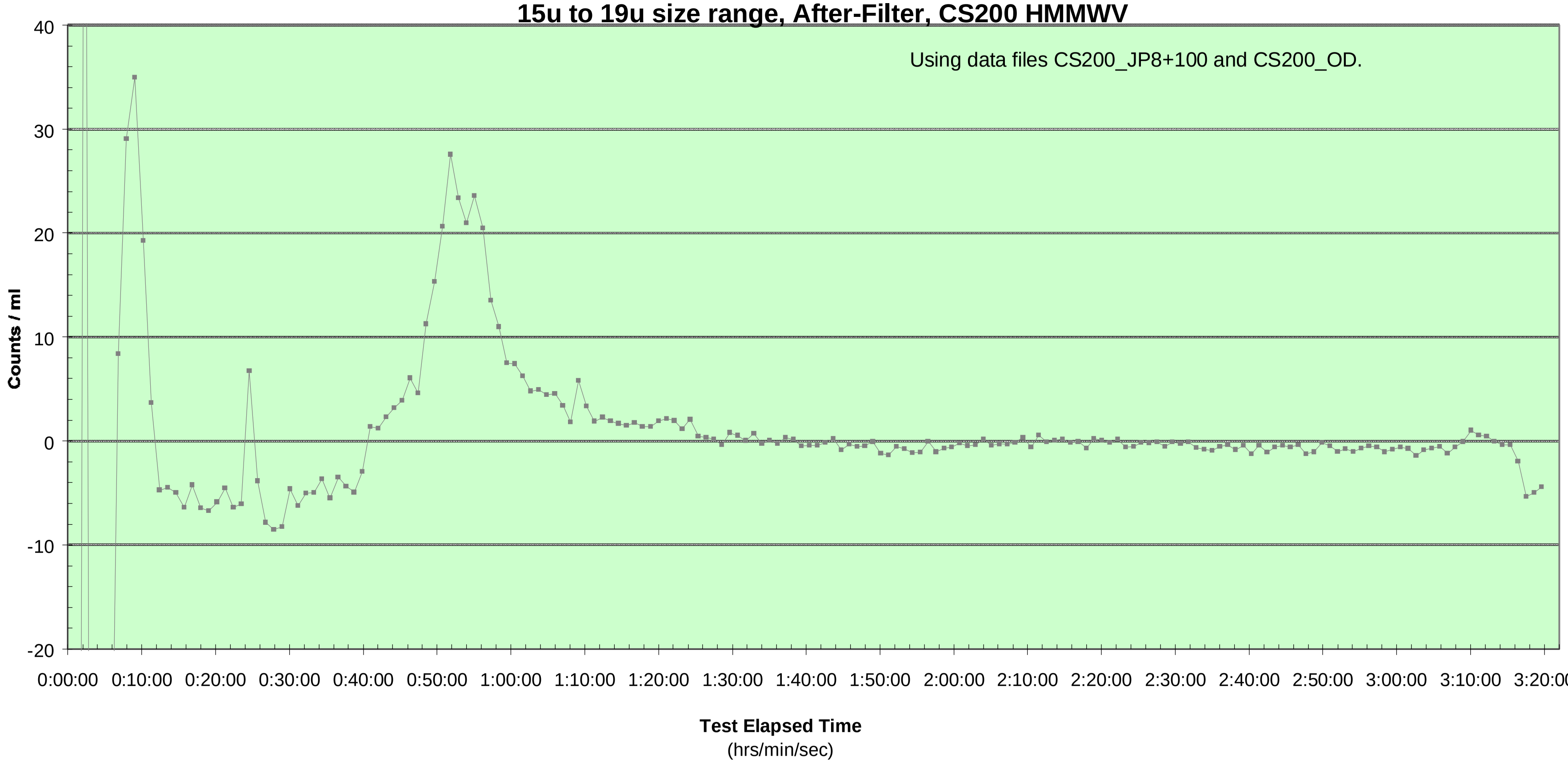


FIGURE 3N

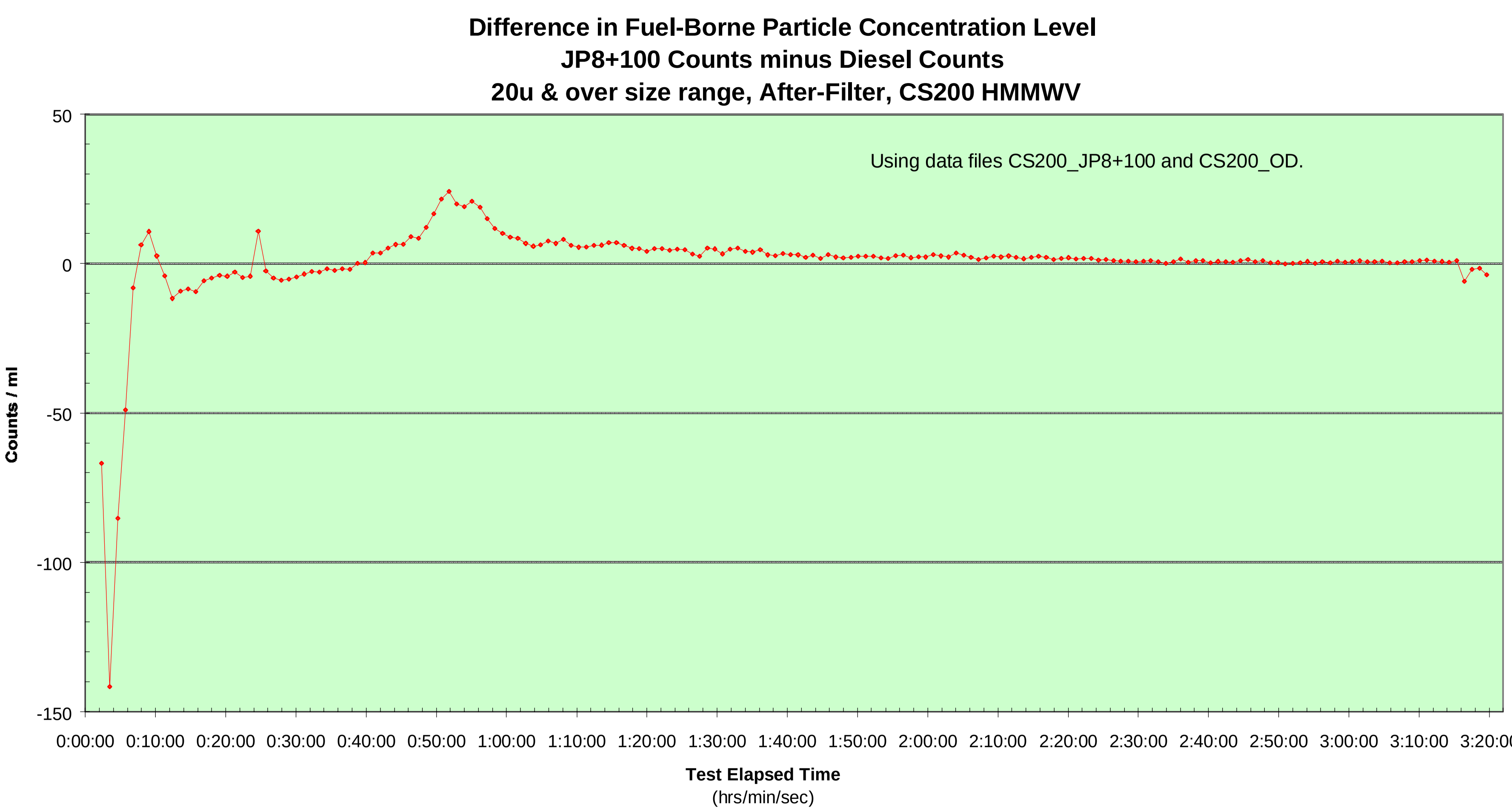
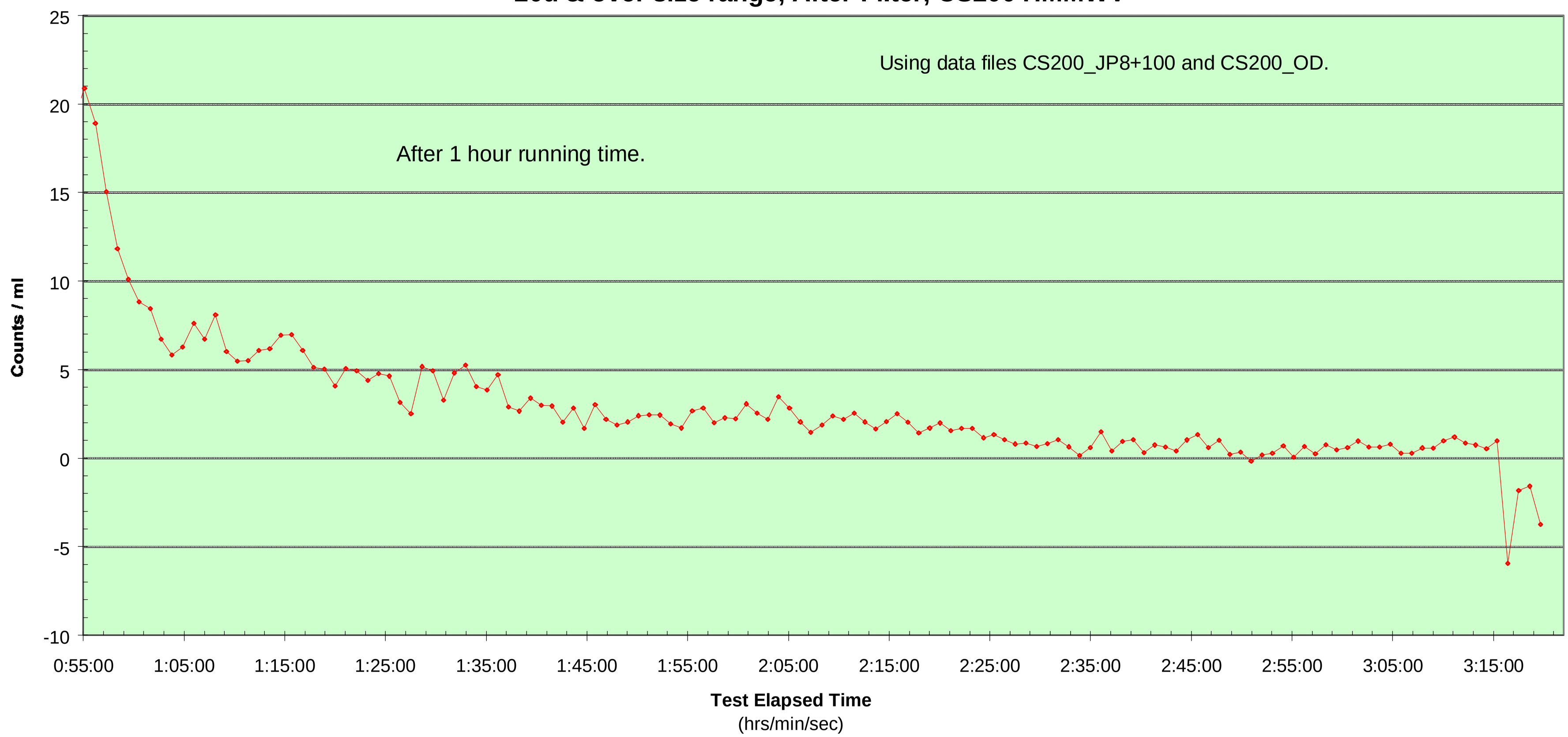

Difference in Fuel-Borne Particle Concentration Level
JP8+100 Counts minus Diesel Counts
20u & over size range, After-Filter, CS200 HMMWV
Using data files CS200_JP8+100 and CS200_OD.
50
0
-50
-100
-150
Counts / ml
0:00:00
0:10:00
0:20:00
0:30:00
0:40:00
0:50:00
1:00:00
1:10:00
1:20:00
1:30:00
1:40:00
1:50:00
2:00:00
2:10:00
2:20:00
2:30:00
2:40:00
2:50:00
3:00:00
3:10:00
3:20:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 3O

Difference in Fuel-Borne Particle Concentration Level (detail)
JP8+100 Counts minus Diesel Counts
20u & over size range, After-Filter, CS200 HMMWV



APPENDIX E

CS100 HMMWV TEST DATA

FIGURE 1A

Original Diesel Idle Test - 3u to 9u
Before-Filter Side

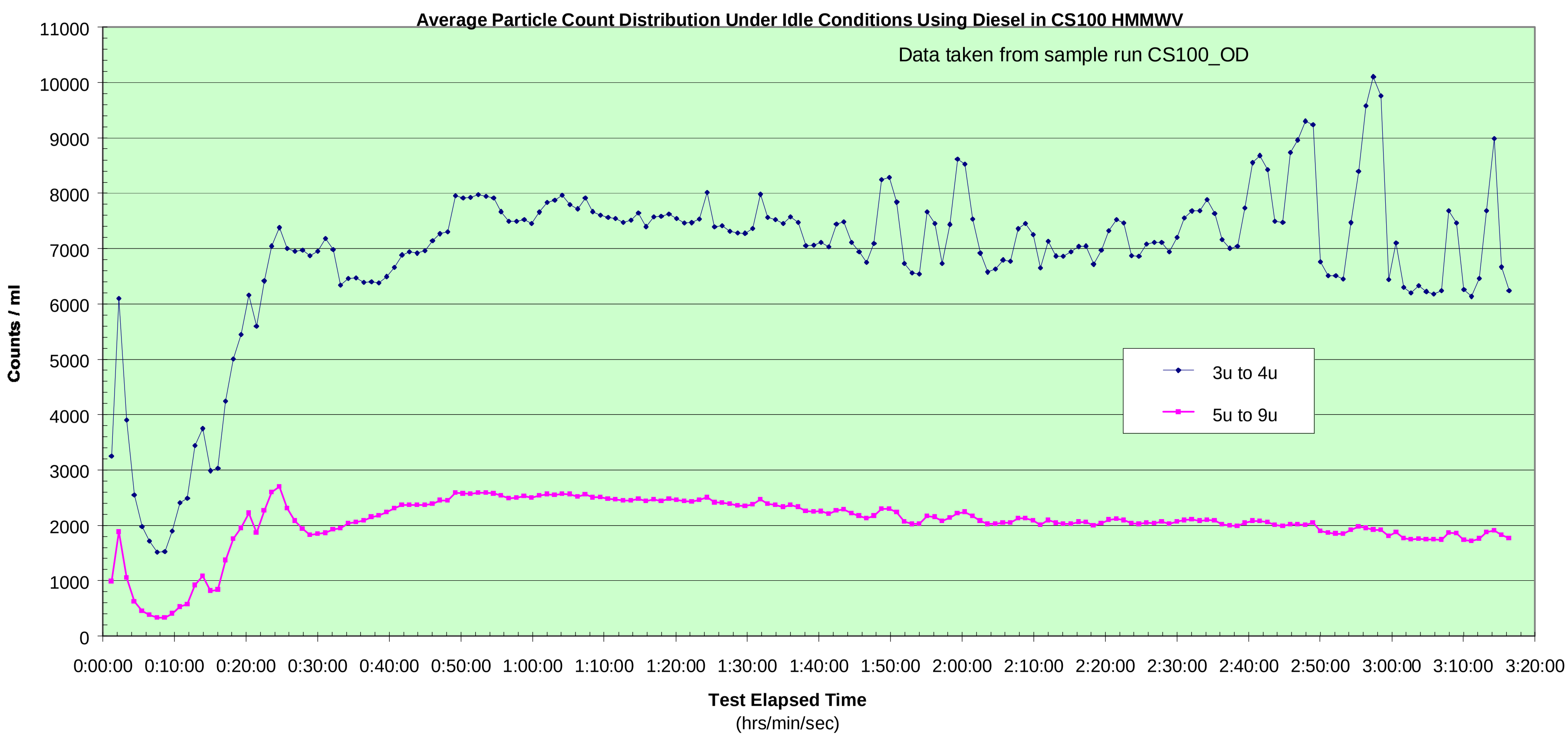
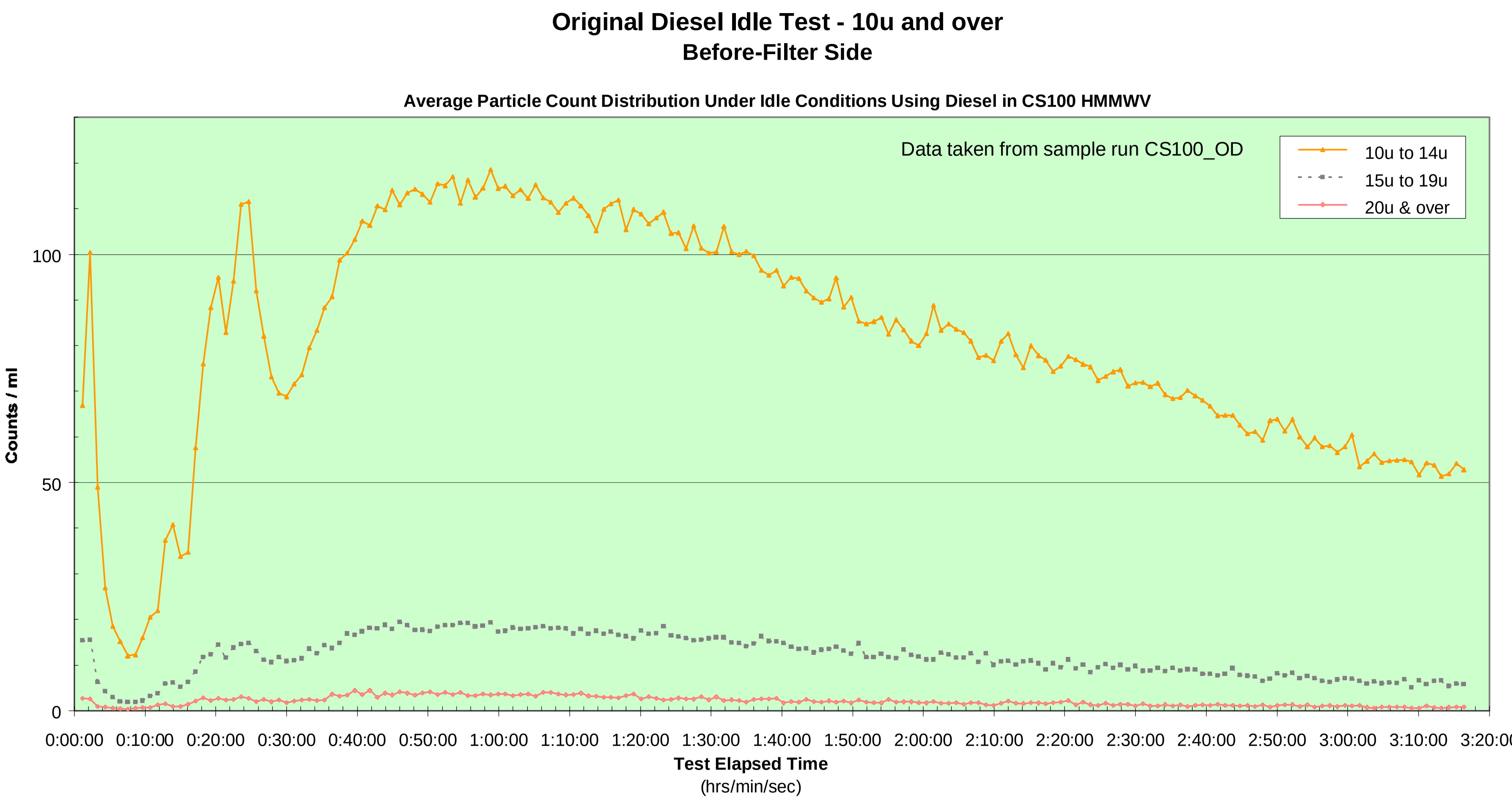
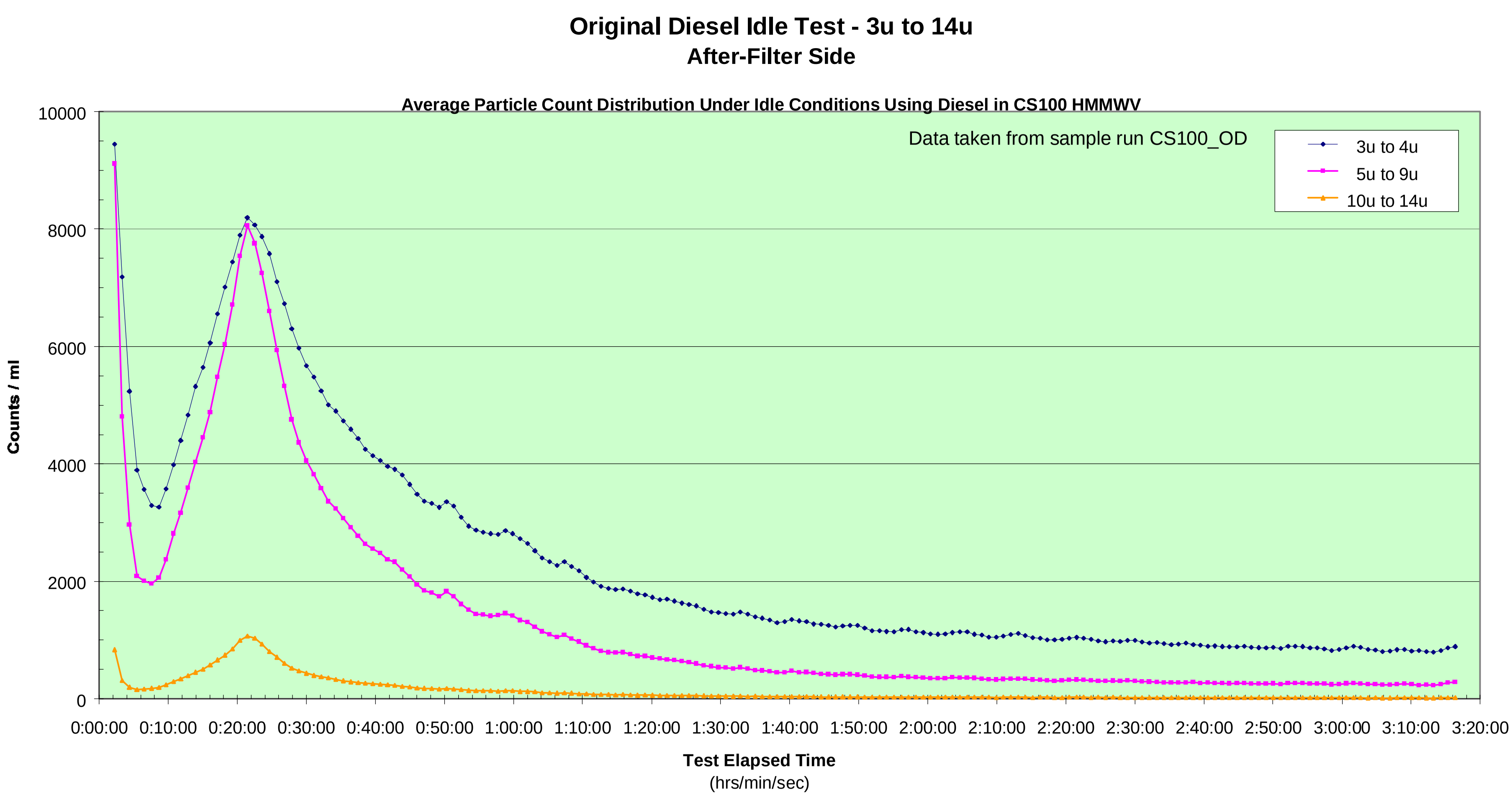


FIGURE 1B



Original Diesel Idle Test - 10u and over
Before-Filter Side
Average Particle Count Distribution Under Idle Conditions Using Diesel in CS100 HMMWV
Data taken from sample run CS100_OD
10u to 14u
15u to 19u
20u & over
Counts / ml
100
50
0
0:00:00
0:10:00
0:20:00
0:30:00
0:40:00
0:50:00
1:00:00
1:10:00
1:20:00
1:30:00
1:40:00
1:50:00
2:00:00
2:10:00
2:20:00
2:30:00
2:40:00
2:50:00
3:00:00
3:10:00
3:20:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 1C



Original Diesel Idle Test - 3u to 14u
After-Filter Side
Average Particle Count Distribution Under Idle Conditions Using Diesel in CS100 HMMWV
Data taken from sample run CS100_OD
3u to 4u
5u to 9u
10u to 14u
Counts / ml
10000
8000
6000
4000
2000
0
0:00:00
0:10:00
0:20:00
0:30:00
0:40:00
0:50:00
1:00:00
1:10:00
1:20:00
1:30:00
1:40:00
1:50:00
2:00:00
2:10:00
2:20:00
2:30:00
2:40:00
2:50:00
3:00:00
3:10:00
3:20:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 1D

Original Diesel Idle Test - 10u & over
After-Filter Side

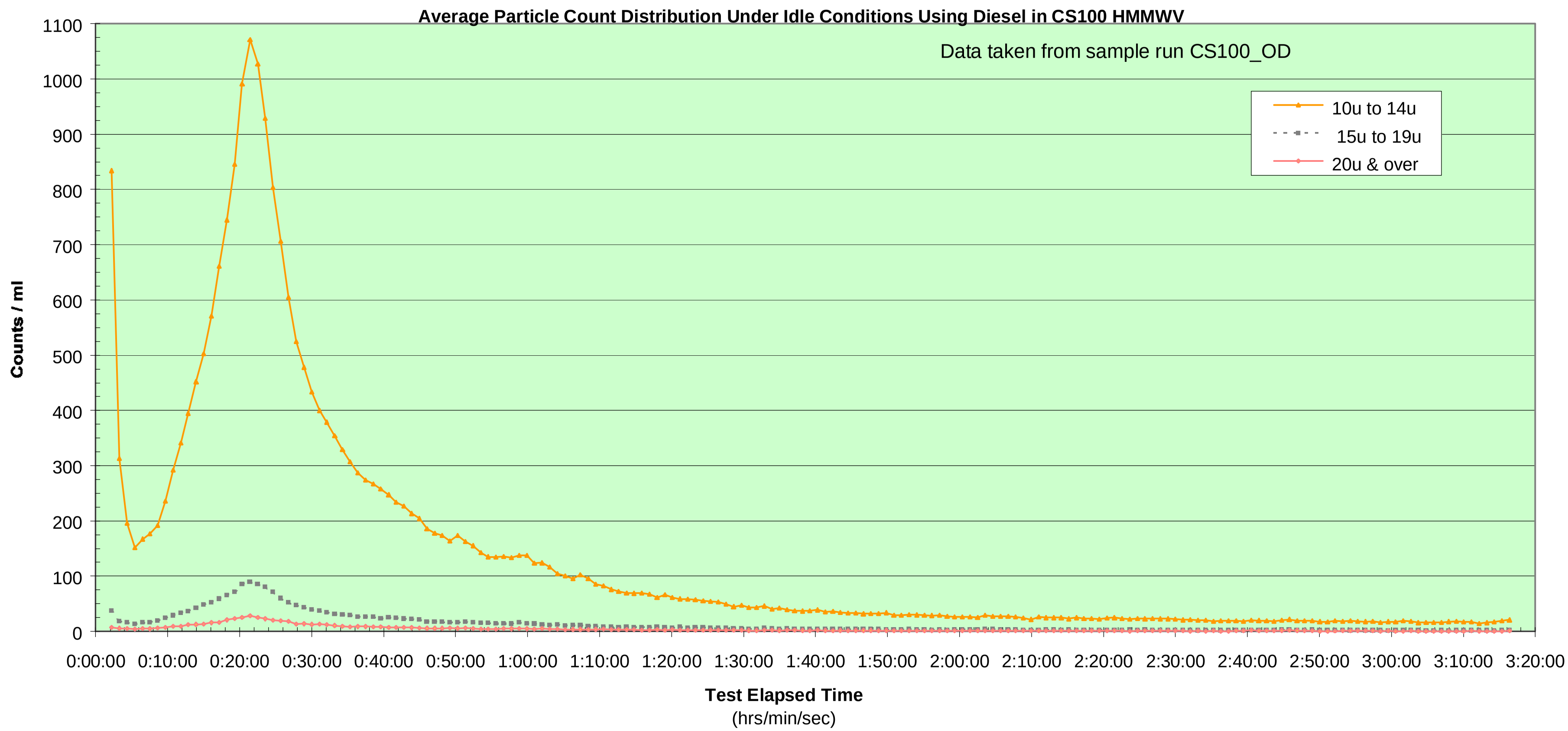


FIGURE 1E

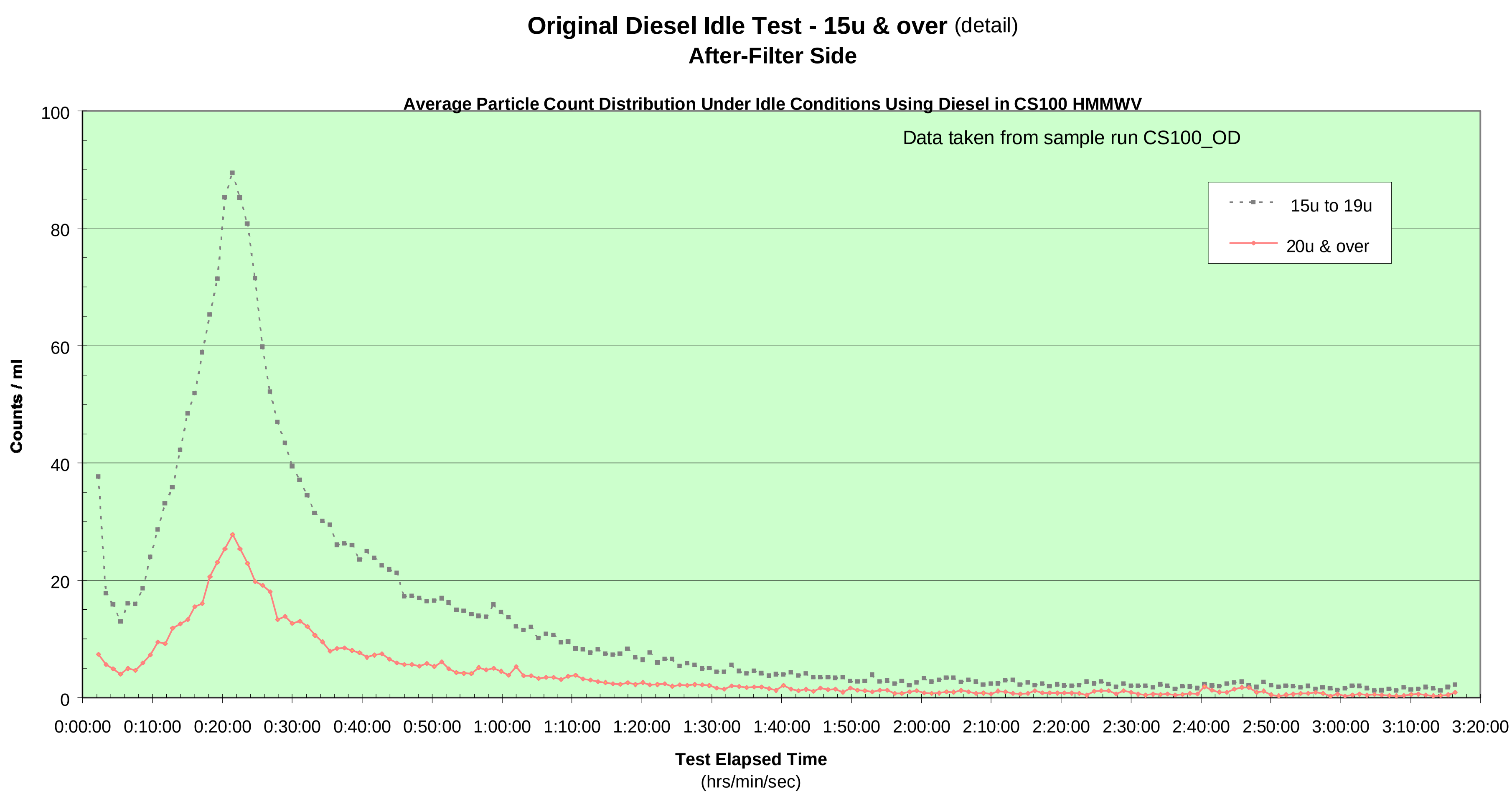

Original Diesel Idle Test - 15u & over (detail)
After-Filter Side
Average Particle Count Distribution Under Idle Conditions Using Diesel in CS100 HMMWV
Data taken from sample run CS100_OD
15u to 19u
20u & over
Counts / ml
0
20
40
60
80
100
0:00:00
0:10:00
0:20:00
0:30:00
0:40:00
0:50:00
1:00:00
1:10:00
1:20:00
1:30:00
1:40:00
1:50:00
2:00:00
2:10:00
2:20:00
2:30:00
2:40:00
2:50:00
3:00:00
3:10:00
3:20:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 1F

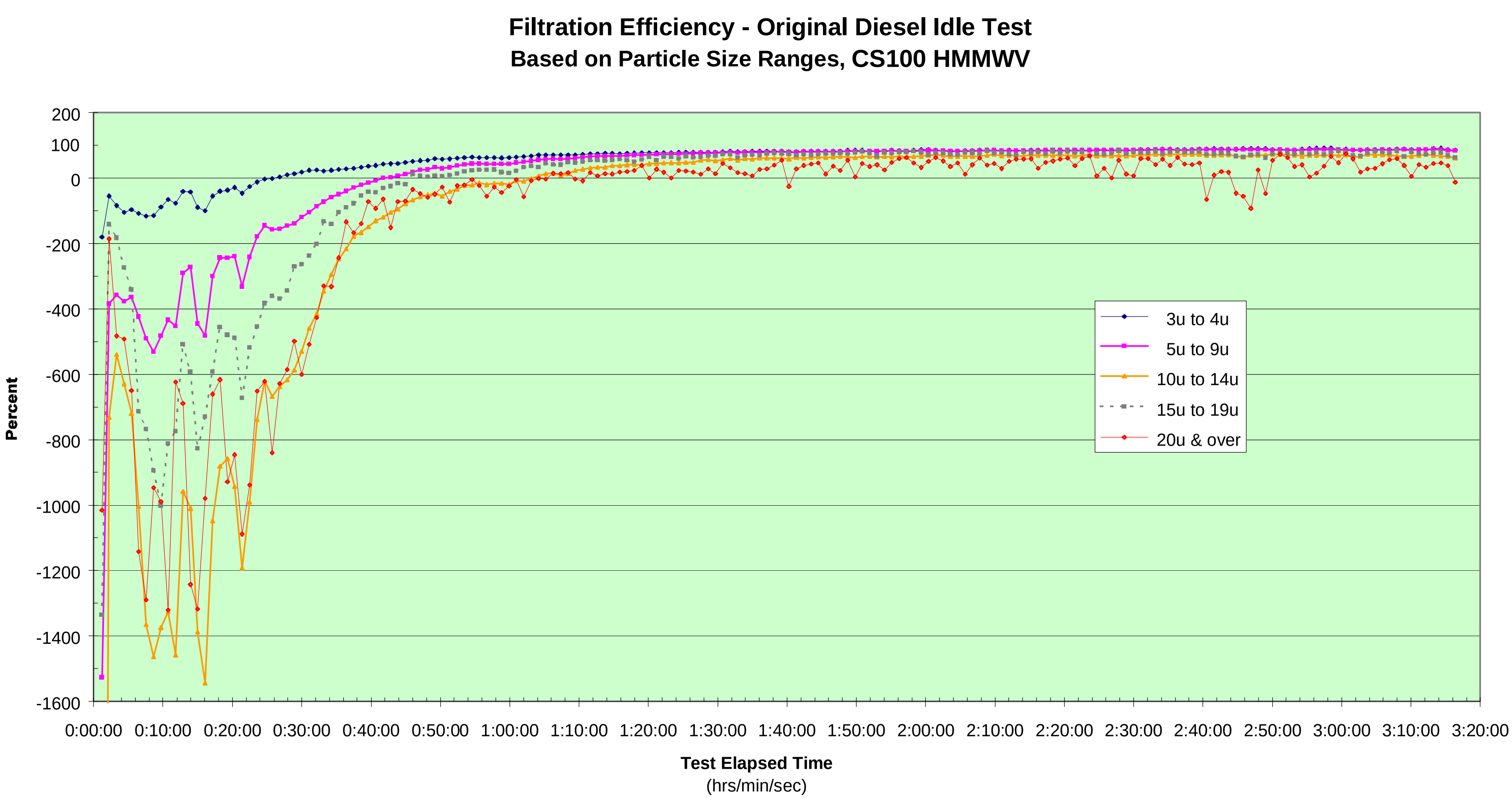

Filtration Efficiency - Original Diesel Idle Test
Based on Particle Size Ranges, CS100 HMMWV
Percent
200
100
0
-200
-400
-600
-800
-1000
-1200
-1400
-1600
0:00:00
0:10:00
0:20:00
0:30:00
0:40:00
0:50:00
1:00:00
1:10:00
1:20:00
1:30:00
1:40:00
1:50:00
2:00:00
2:10:00
2:20:00
2:30:00
2:40:00
2:50:00
3:00:00
3:10:00
3:20:00
Test Elapsed Time
(hrs/min/sec)
3u to 4u
5u to 9u
10u to 14u
15u to 19u
20u & over

FIGURE 1G

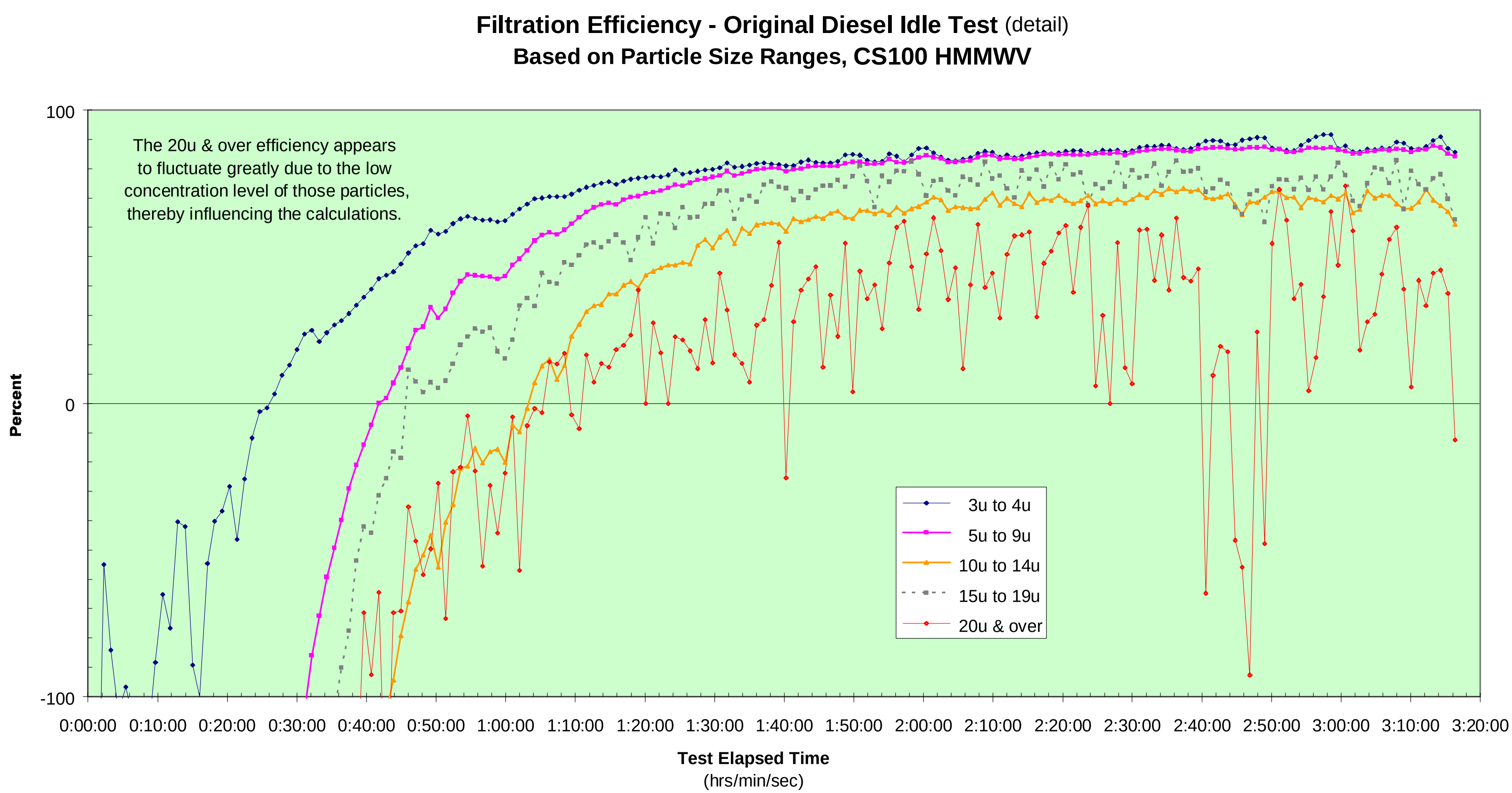

Filtration Efficiency - Original Diesel Idle Test (detail)
Based on Particle Size Ranges, CS100 HMMWV
The 20u & over efficiency appears to fluctuate greatly due to the low concentration level of those particles, thereby influencing the calculations.
Percent
100
0
-100
3u to 4u
5u to 9u
10u to 14u
15u to 19u
20u & over
0:00:00
0:10:00
0:20:00
0:30:00
0:40:00
0:50:00
1:00:00
1:10:00
1:20:00
1:30:00
1:40:00
1:50:00
2:00:00
2:10:00
2:20:00
2:30:00
2:40:00
2:50:00
3:00:00
3:10:00
3:20:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 2A

JP8-neat Idle Test - 3u to 14u
Before-Filter Side

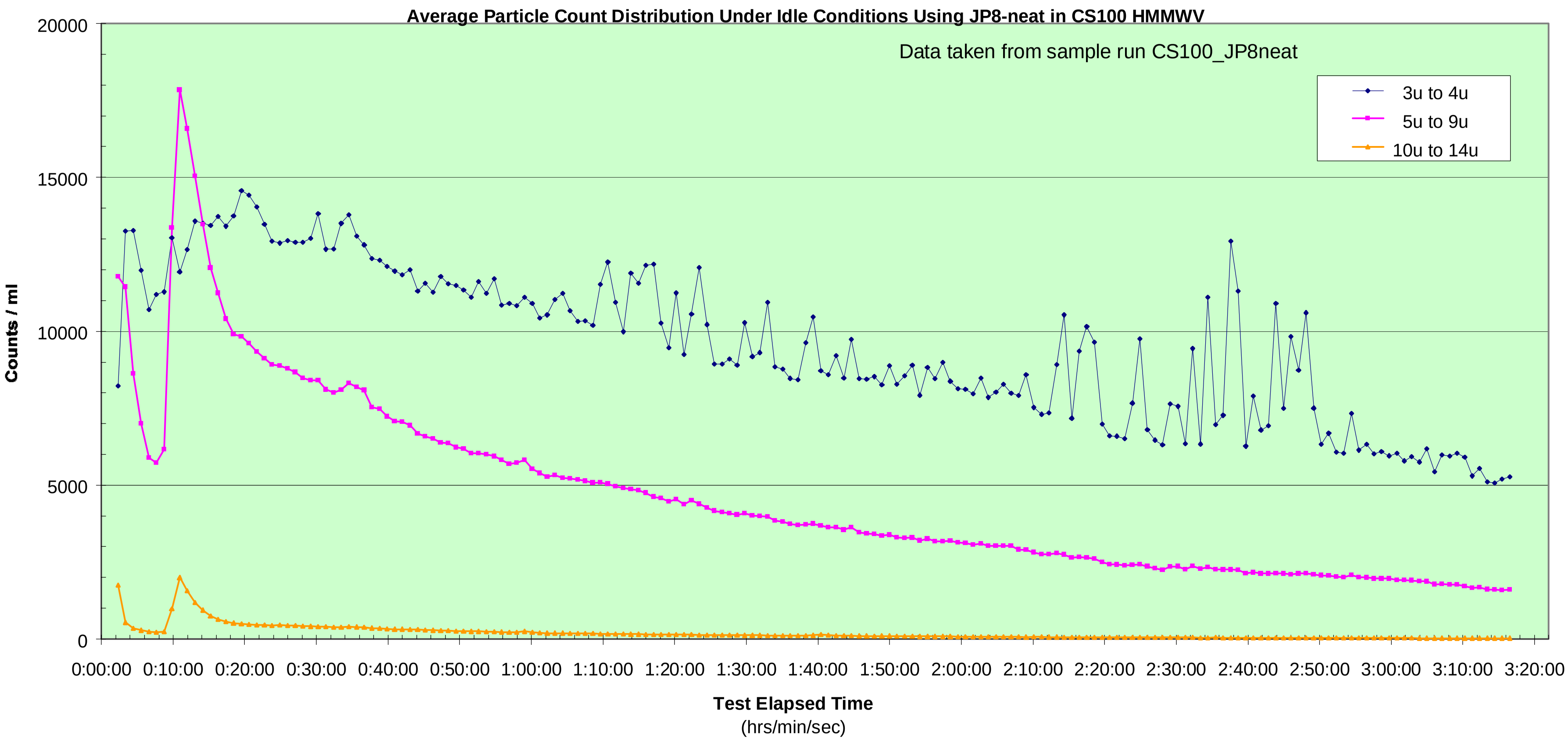


FIGURE 2B

JP8-neat Idle Test - 10u to 19u (detail)
Before-Filter Side

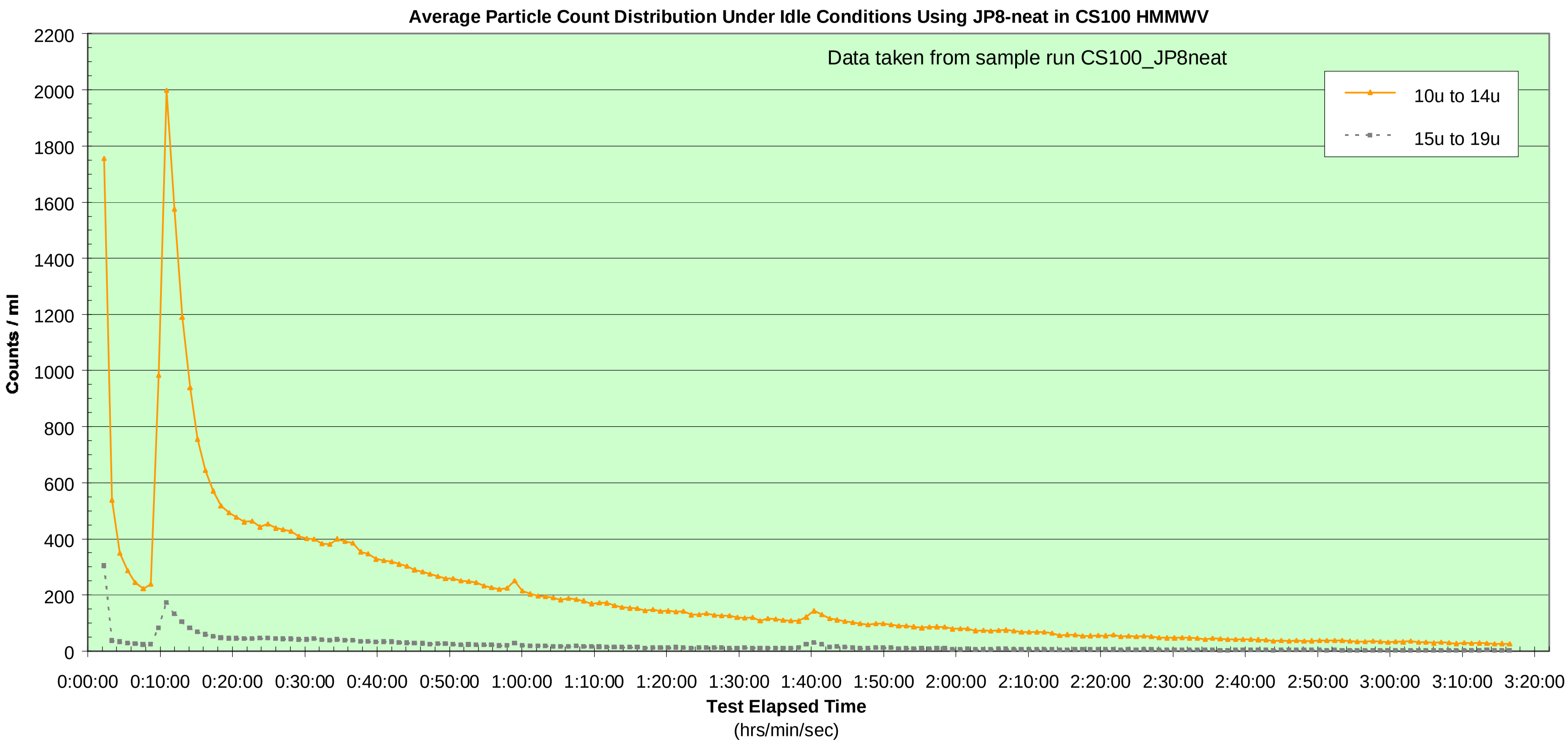


FIGURE 2C

JP8-neat Idle Test - 15u & over
Before-Filter Side

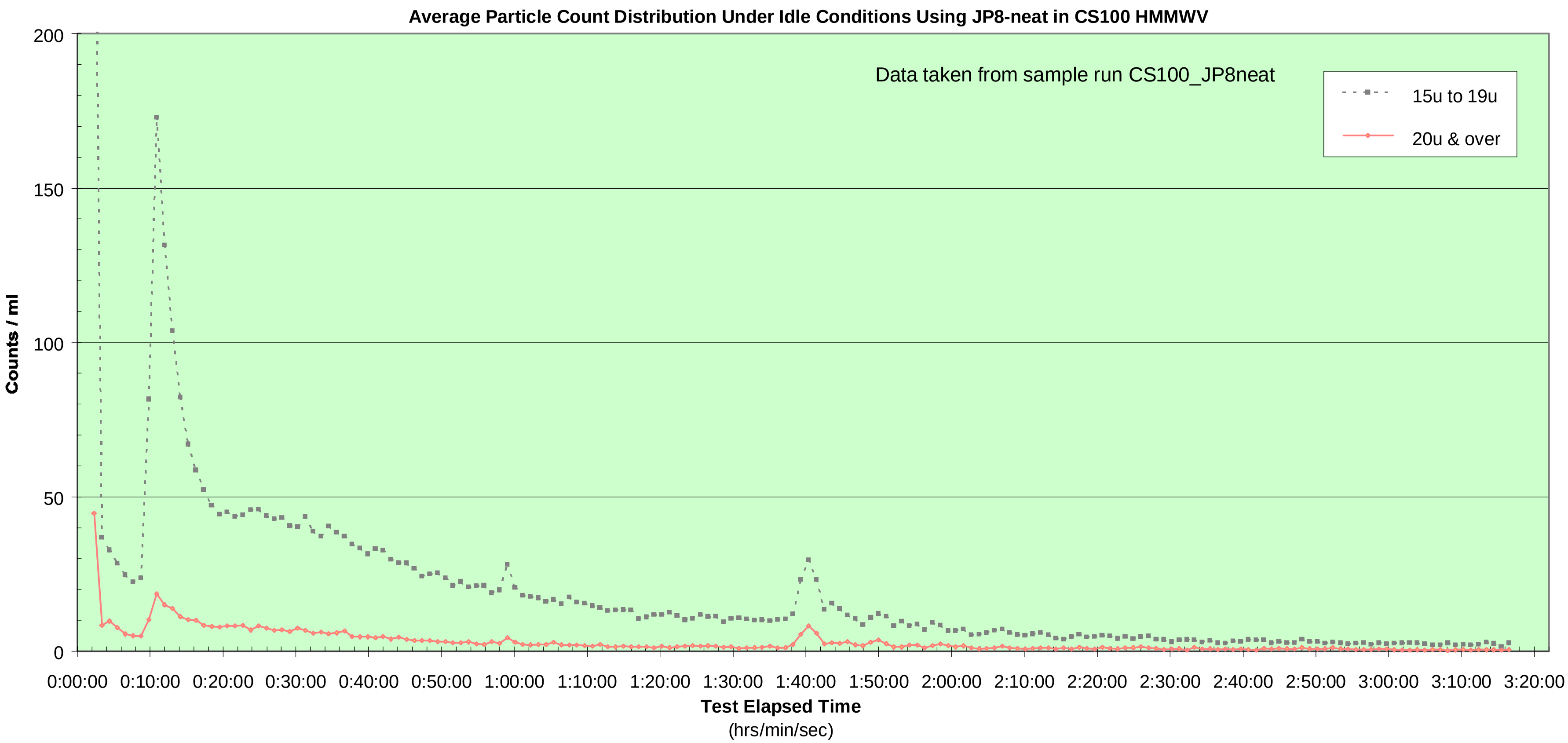
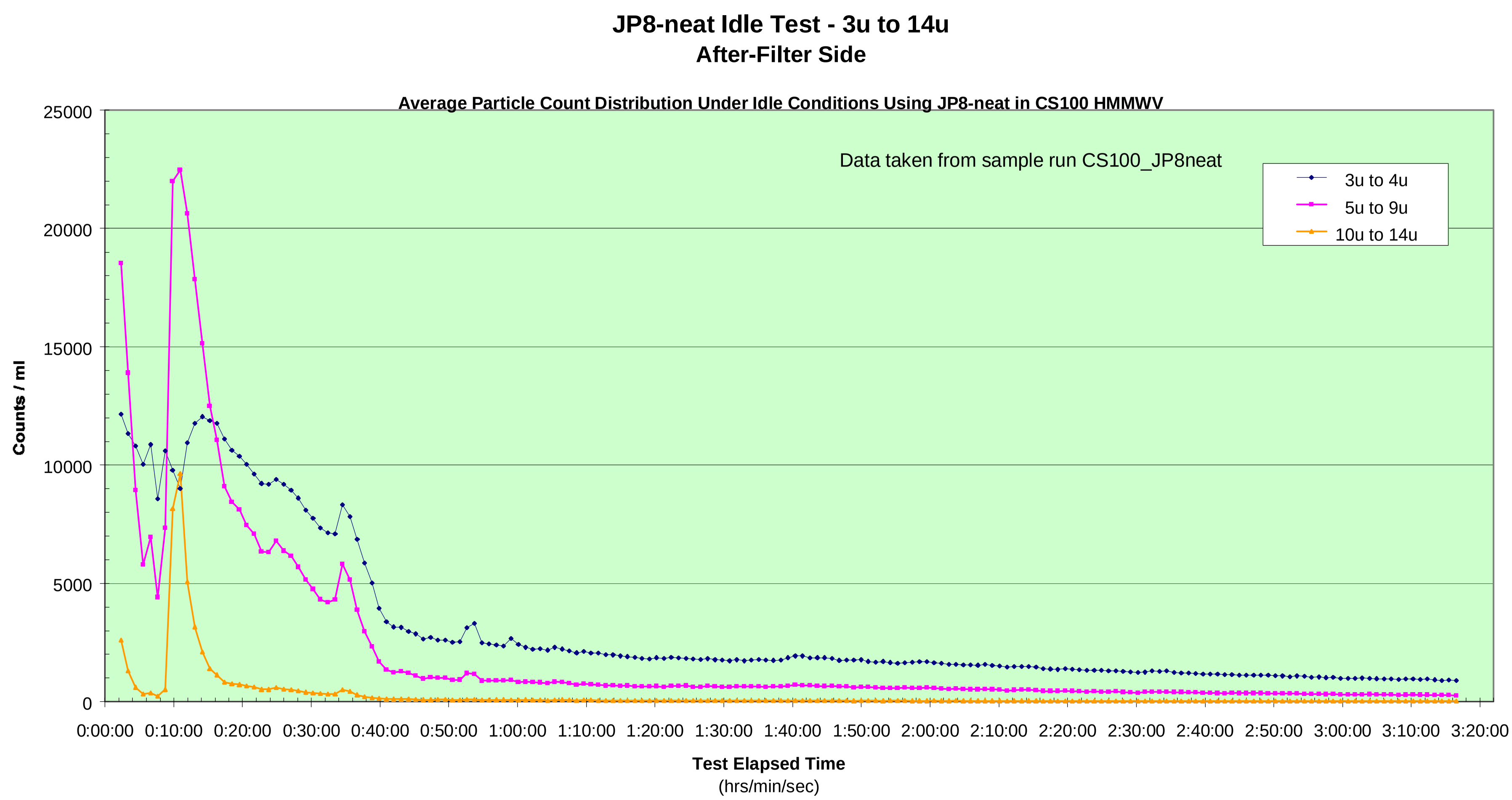


FIGURE 2D



JP8-neat Idle Test - 3u to 14u
After-Filter Side
Average Particle Count Distribution Under Idle Conditions Using JP8-neat in CS100 HMMWV
Data taken from sample run CS100_JP8neat
3u to 4u
5u to 9u
10u to 14u
Counts / ml
0
5000
10000
15000
20000
25000
0:00:00
0:10:00
0:20:00
0:30:00
0:40:00
0:50:00
1:00:00
1:10:00
1:20:00
1:30:00
1:40:00
1:50:00
2:00:00
2:10:00
2:20:00
2:30:00
2:40:00
2:50:00
3:00:00
3:10:00
3:20:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 2E

JP8-neat Idle Test - 10u to 19u (detail)
After-Filter Side

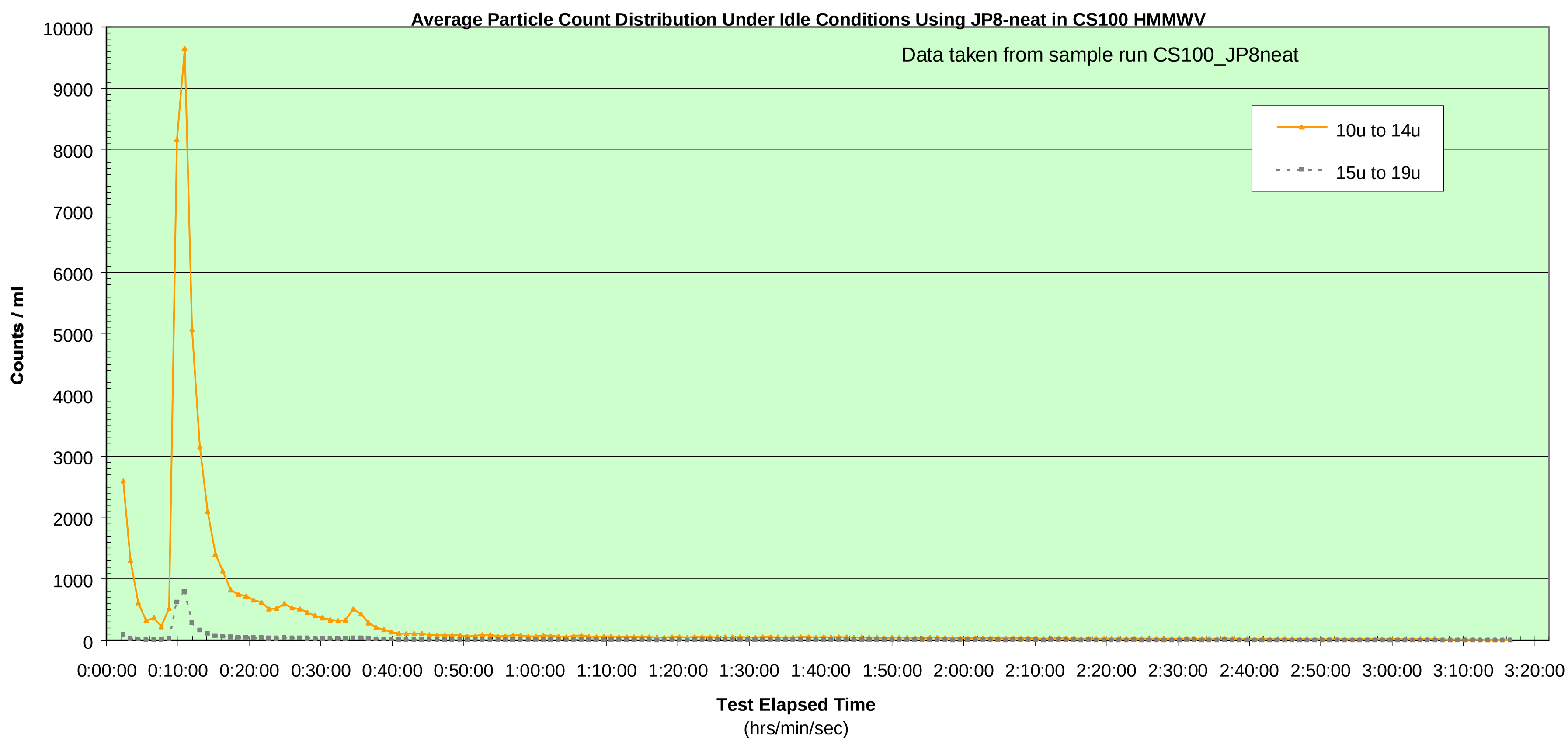


FIGURE 2F

JP8-neat Idle Test - 10u & over (detail)
After-Filter Side

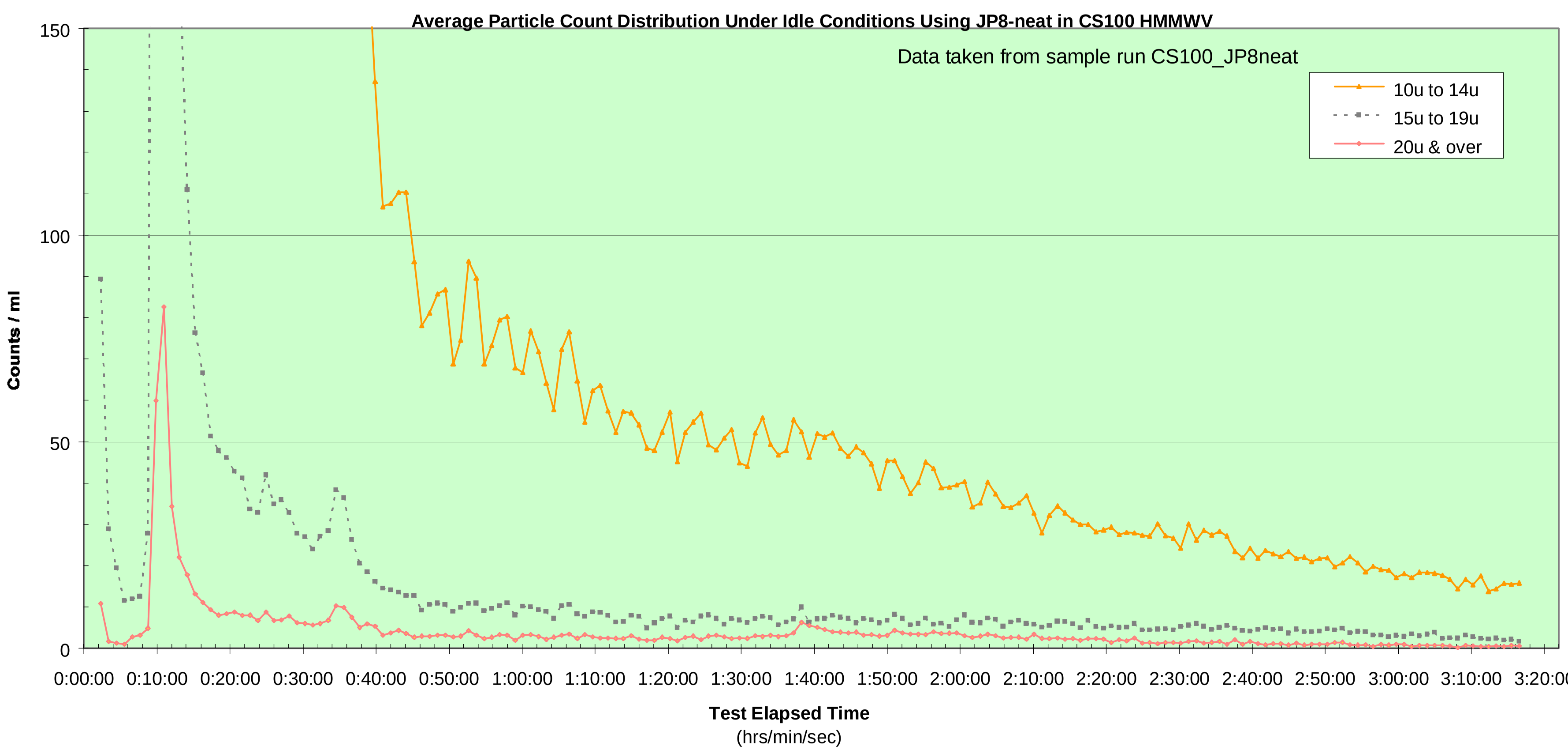


FIGURE 2G

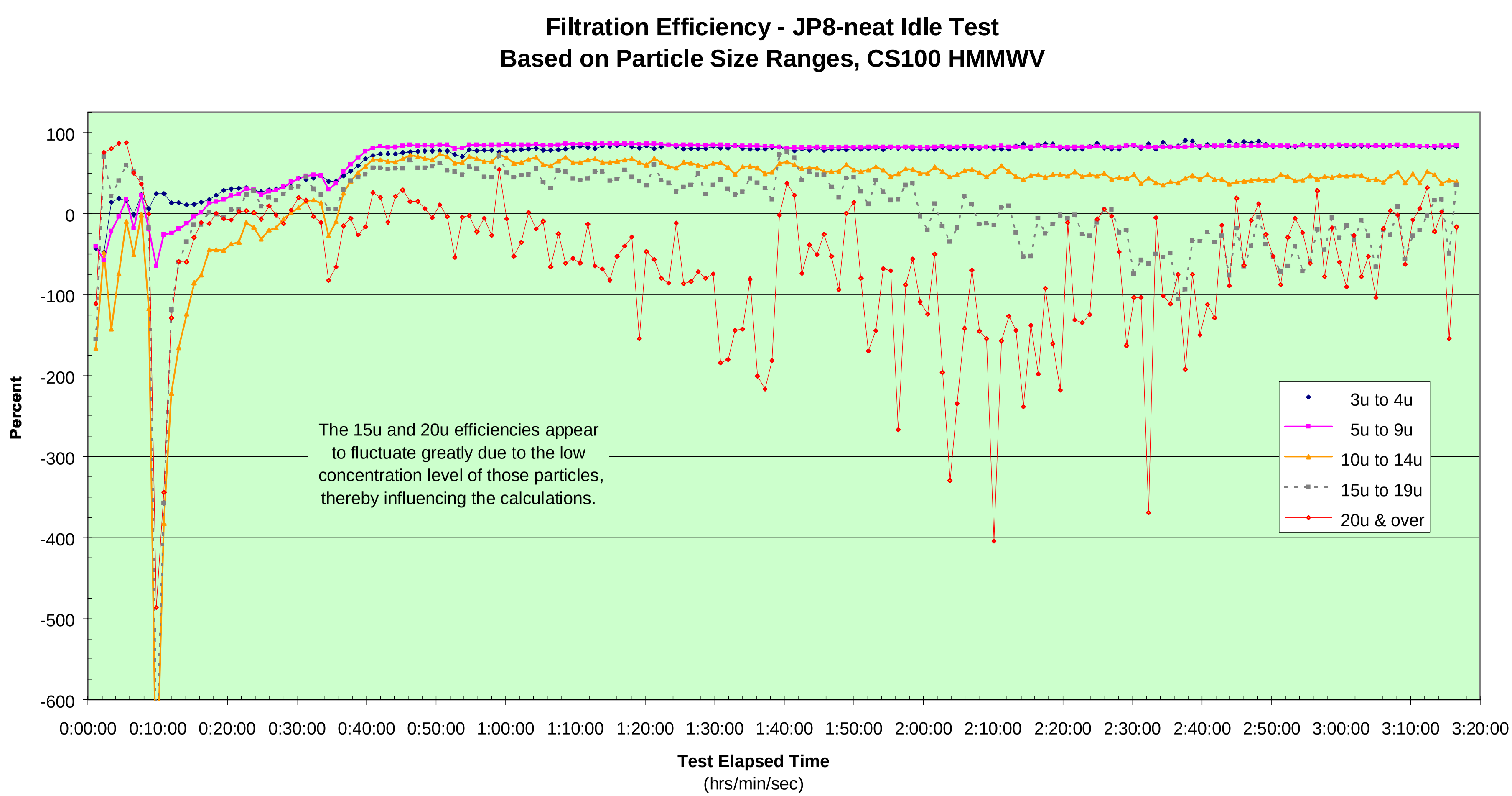

Filtration Efficiency - JP8-neat Idle Test
Based on Particle Size Ranges, CS100 HMMWV
Percent
100
0
-100
-200
-300
-400
-500
-600
0:00:00
0:10:00
0:20:00
0:30:00
0:40:00
0:50:00
1:00:00
1:10:00
1:20:00
1:30:00
1:40:00
1:50:00
2:00:00
2:10:00
2:20:00
2:30:00
2:40:00
2:50:00
3:00:00
3:10:00
3:20:00
Test Elapsed Time
(hrs/min/sec)
3u to 4u
5u to 9u
10u to 14u
15u to 19u
20u & over
The 15u and 20u efficiencies appear to fluctuate greatly due to the low concentration level of those particles, thereby influencing the calculations.

FIGURE 3A

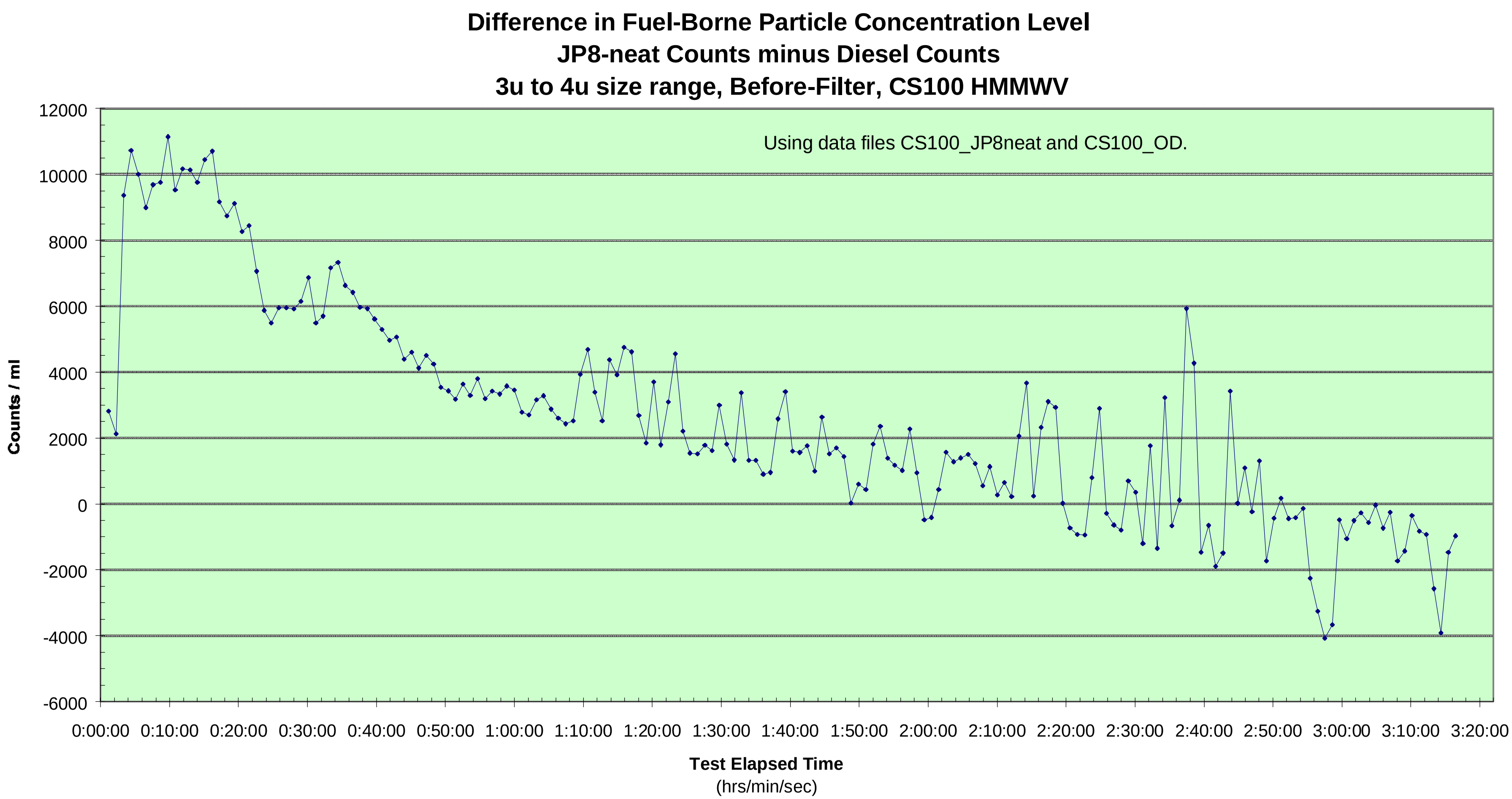

Difference in Fuel-Borne Particle Concentration Level
JP8-neat Counts minus Diesel Counts
3u to 4u size range, Before-Filter, CS100 HMMWV
Using data files CS100_JP8neat and CS100_OD.
Counts / ml
12000
10000
8000
6000
4000
2000
0
-2000
-4000
-6000
0:00:00 0:10:00 0:20:00 0:30:00 0:40:00 0:50:00 1:00:00 1:10:00 1:20:00 1:30:00 1:40:00 1:50:00 2:00:00 2:10:00 2:20:00 2:30:00 2:40:00 2:50:00 3:00:00 3:10:00 3:20:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 3B

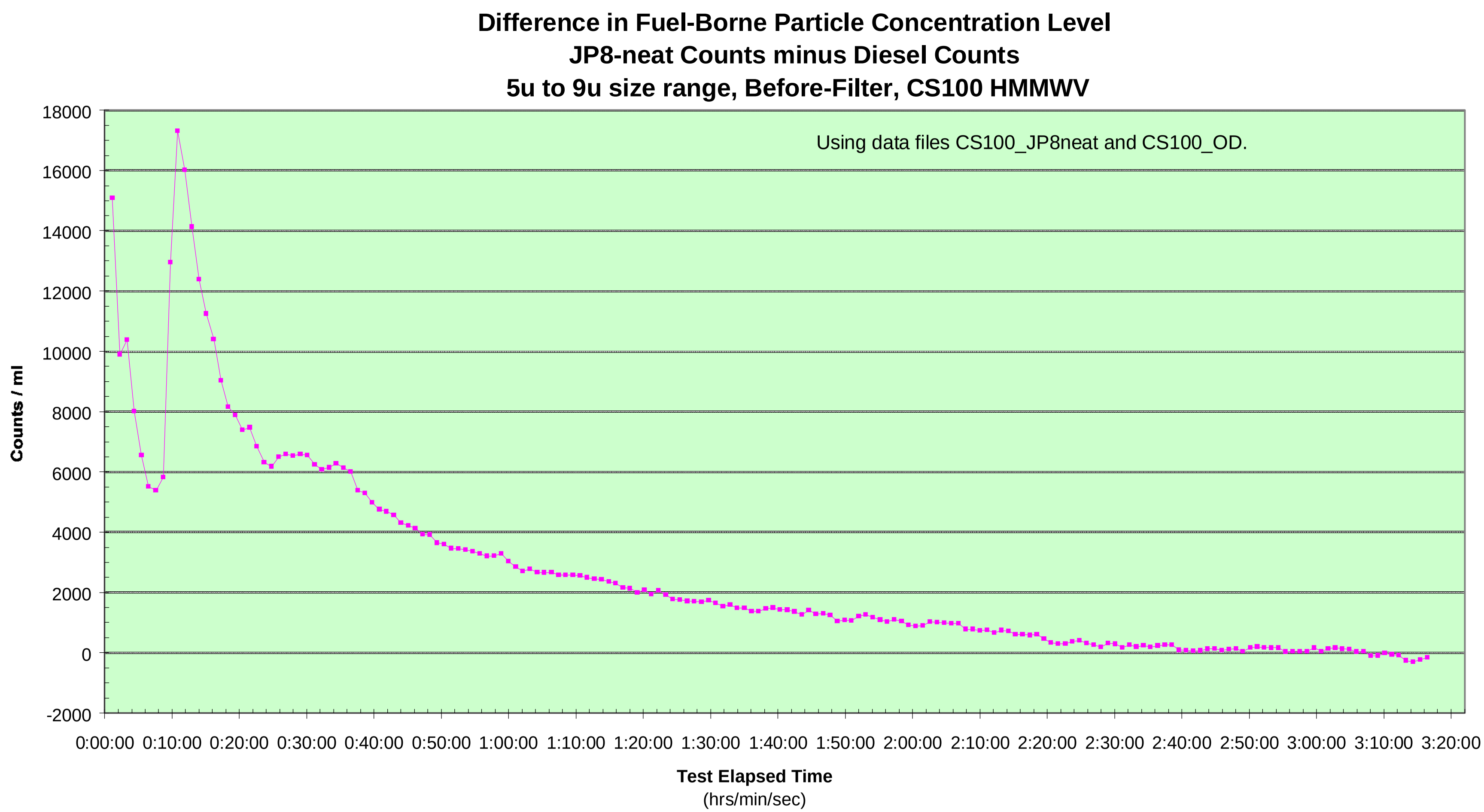
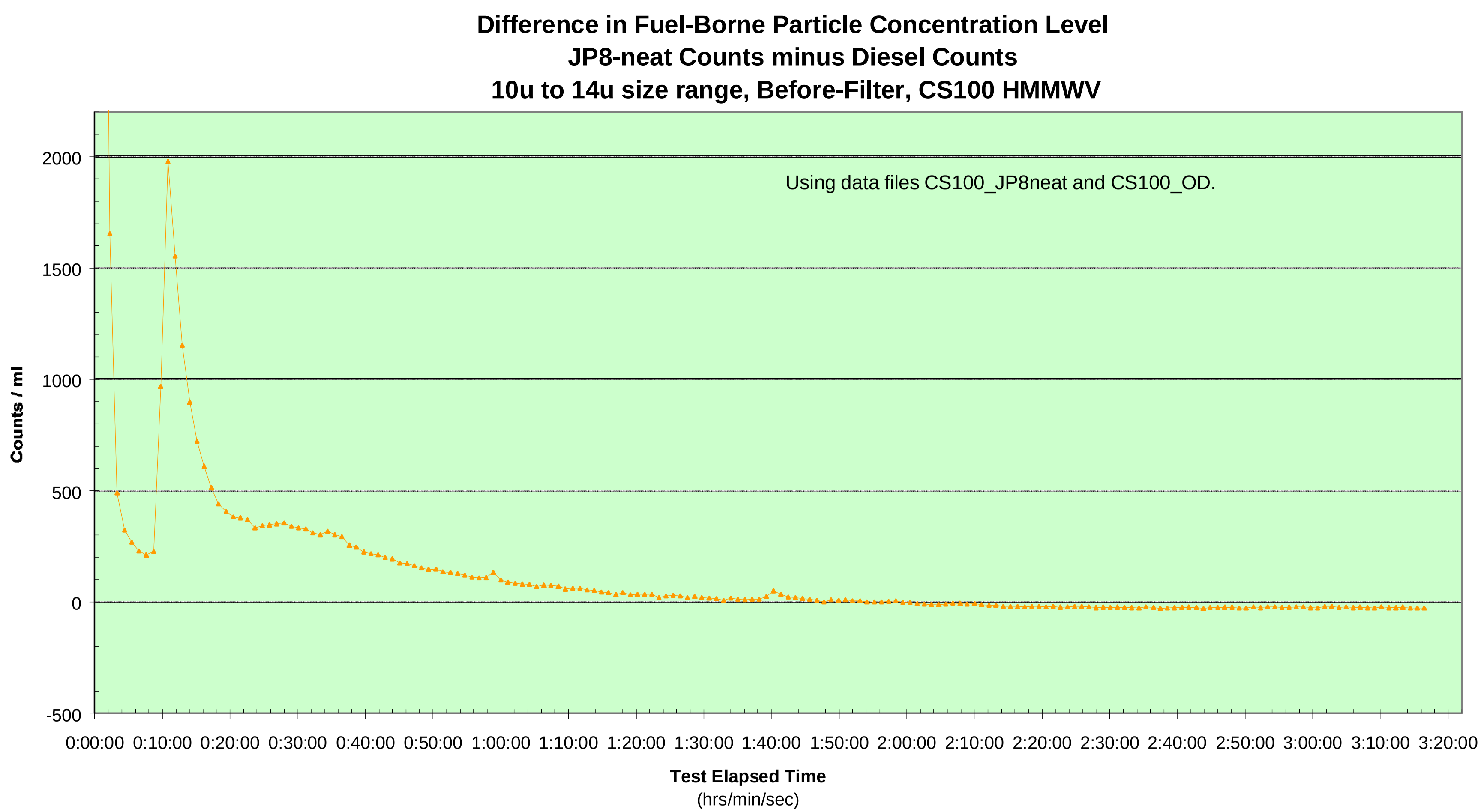

Difference in Fuel-Borne Particle Concentration Level
JP8-neat Counts minus Diesel Counts
5u to 9u size range, Before-Filter, CS100 HMMWV
Using data files CS100_JP8neat and CS100_OD.
Counts / ml
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
-2000
0:00:00 0:10:00 0:20:00 0:30:00 0:40:00 0:50:00 1:00:00 1:10:00 1:20:00 1:30:00 1:40:00 1:50:00 2:00:00 2:10:00 2:20:00 2:30:00 2:40:00 2:50:00 3:00:00 3:10:00 3:20:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 3C



Difference in Fuel-Borne Particle Concentration Level
JP8-neat Counts minus Diesel Counts
10u to 14u size range, Before-Filter, CS100 HMMWV
Using data files CS100_JP8neat and CS100_OD.
Counts / ml
2000
1500
1000
500
0
-500
0:00:00 0:10:00 0:20:00 0:30:00 0:40:00 0:50:00 1:00:00 1:10:00 1:20:00 1:30:00 1:40:00 1:50:00 2:00:00 2:10:00 2:20:00 2:30:00 2:40:00 2:50:00 3:00:00 3:10:00 3:20:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 3D

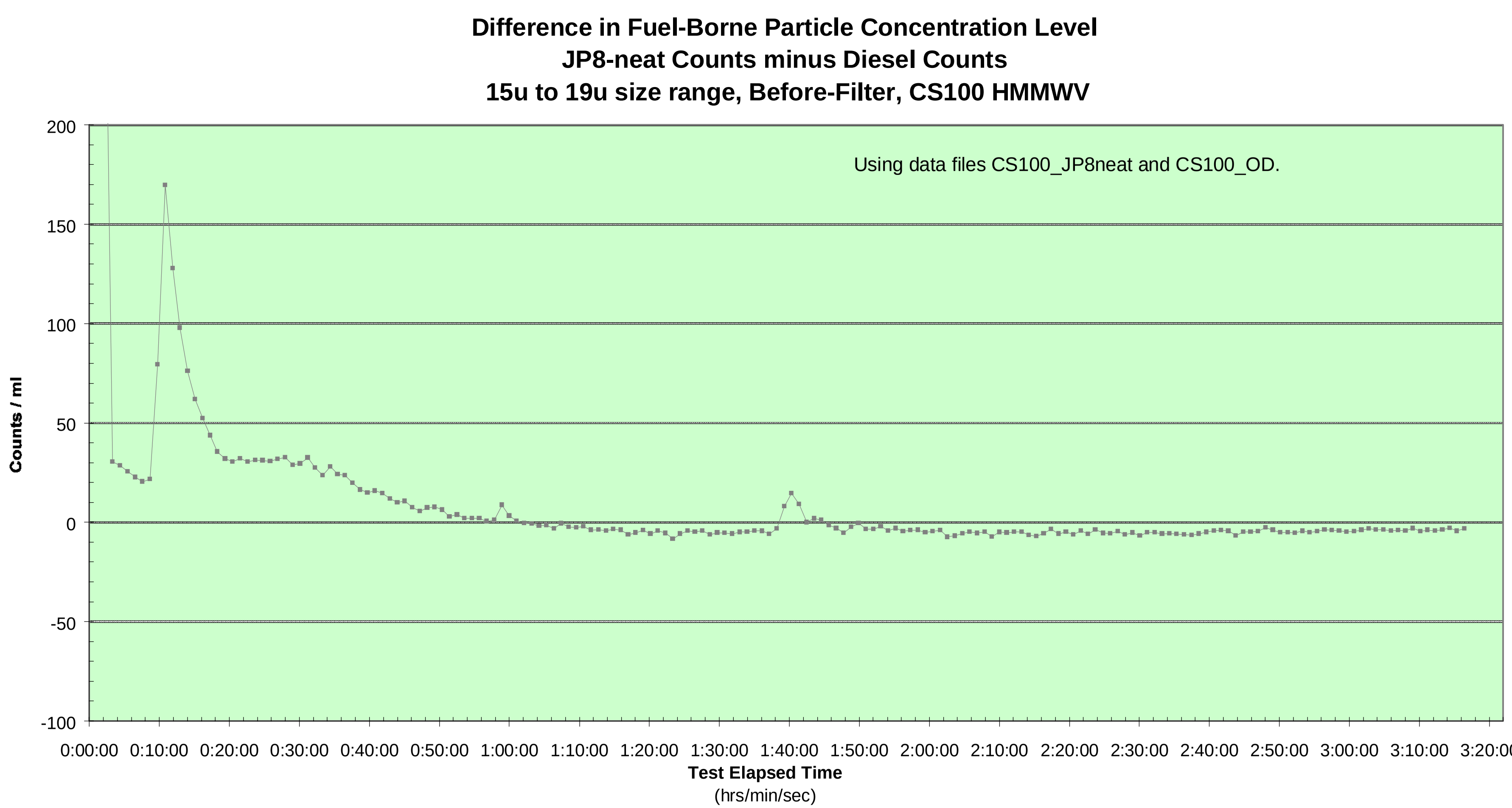

Difference in Fuel-Borne Particle Concentration Level
JP8-neat Counts minus Diesel Counts
15u to 19u size range, Before-Filter, CS100 HMMWV
Using data files CS100_JP8neat and CS100_OD.
Counts / ml
200
150
100
50
0
-50
-100
0:00:00
0:10:00
0:20:00
0:30:00
0:40:00
0:50:00
1:00:00
1:10:00
1:20:00
1:30:00
1:40:00
1:50:00
2:00:00
2:10:00
2:20:00
2:30:00
2:40:00
2:50:00
3:00:00
3:10:00
3:20:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 3E

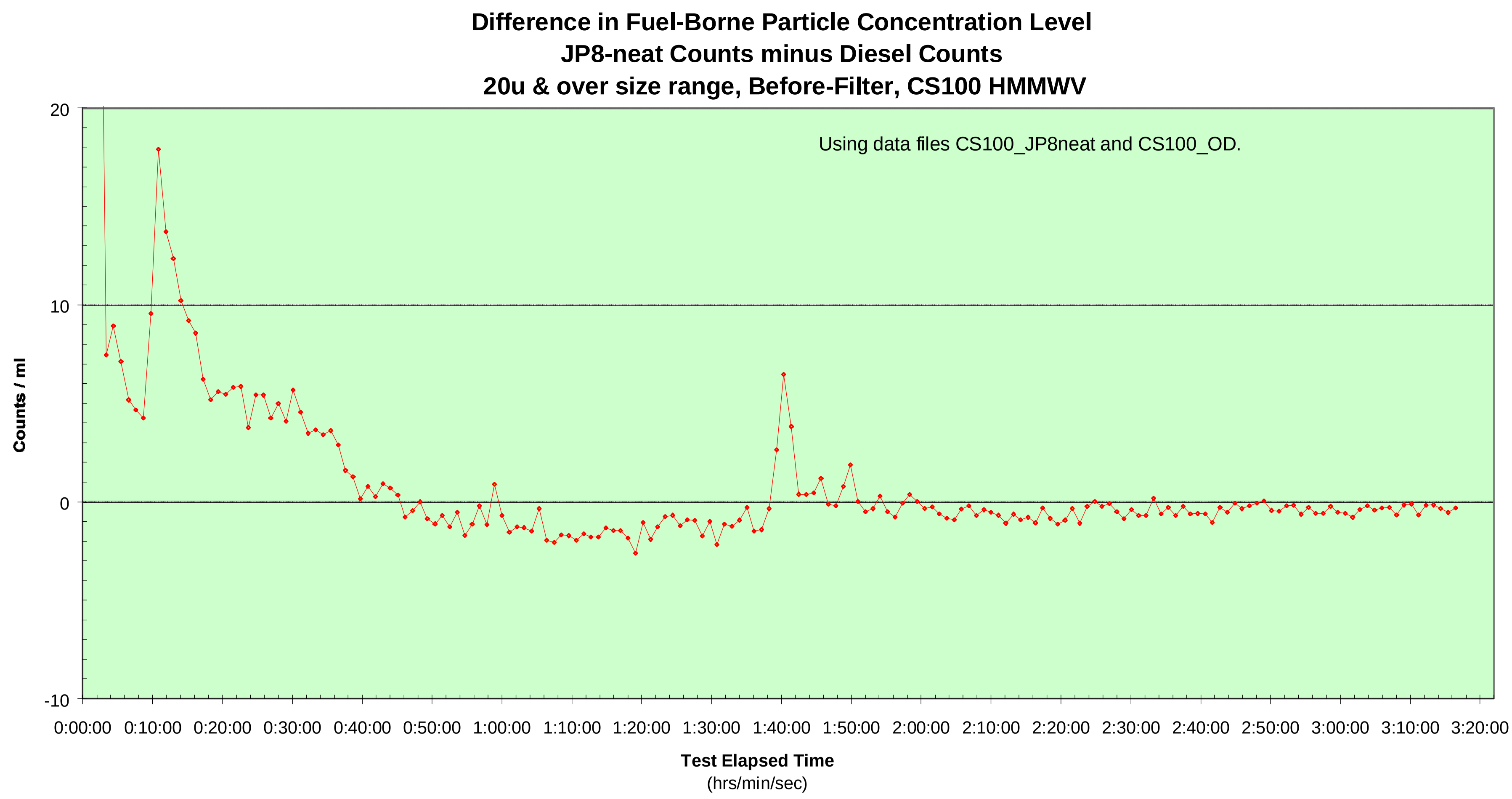

Difference in Fuel-Borne Particle Concentration Level
JP8-neat Counts minus Diesel Counts
20u & over size range, Before-Filter, CS100 HMMWV
Using data files CS100_JP8neat and CS100_OD.
Counts / ml
20
10
0
-10
0:00:00
0:10:00
0:20:00
0:30:00
0:40:00
0:50:00
1:00:00
1:10:00
1:20:00
1:30:00
1:40:00
1:50:00
2:00:00
2:10:00
2:20:00
2:30:00
2:40:00
2:50:00
3:00:00
3:10:00
3:20:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 3F

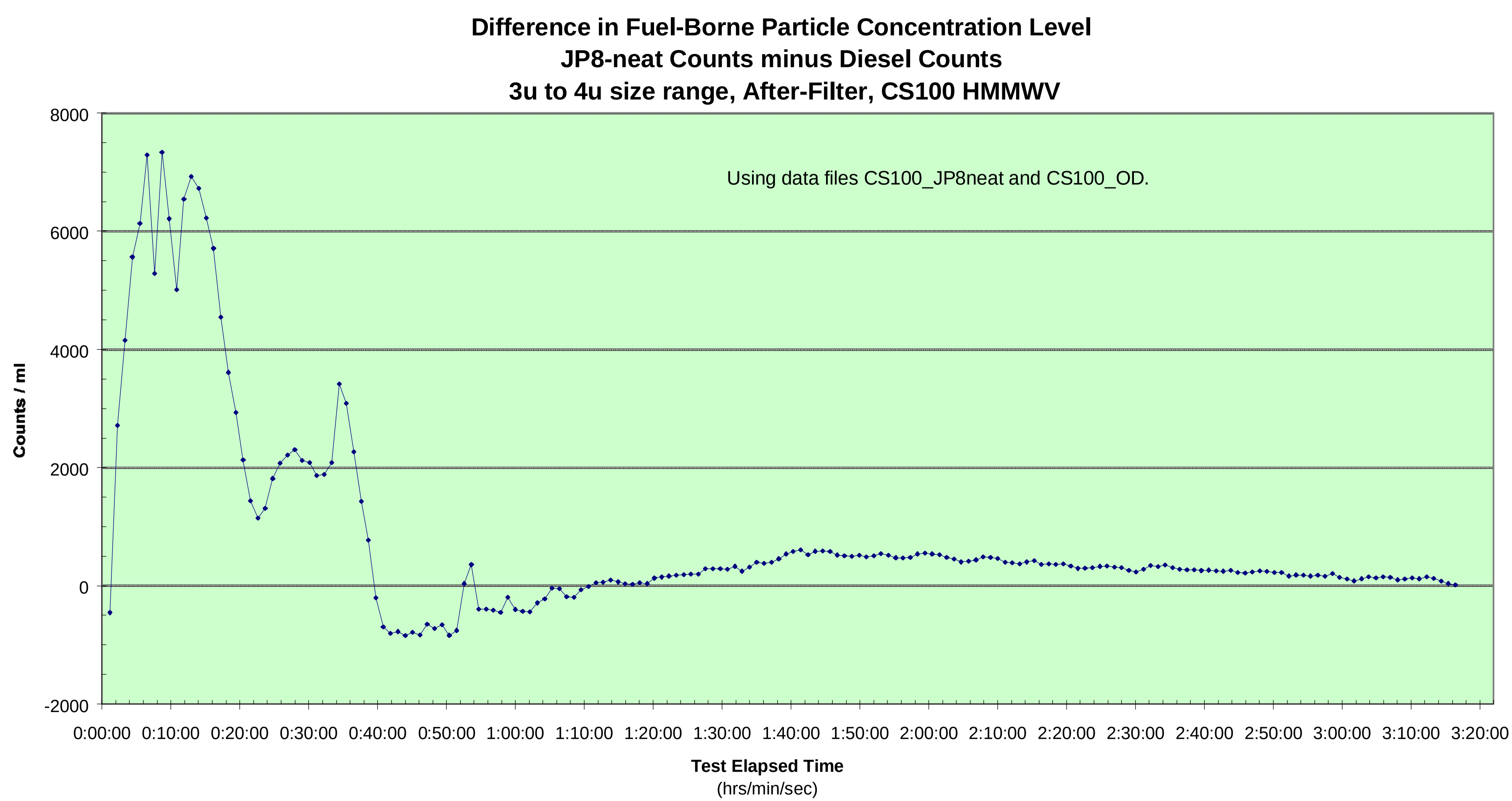

Difference in Fuel-Borne Particle Concentration Level
JP8-neat Counts minus Diesel Counts
3u to 4u size range, After-Filter, CS100 HMMWV
Using data files CS100_JP8neat and CS100_OD.
Counts / ml
8000
6000
4000
2000
0
-2000
0:00:00
0:10:00
0:20:00
0:30:00
0:40:00
0:50:00
1:00:00
1:10:00
1:20:00
1:30:00
1:40:00
1:50:00
2:00:00
2:10:00
2:20:00
2:30:00
2:40:00
2:50:00
3:00:00
3:10:00
3:20:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 3G

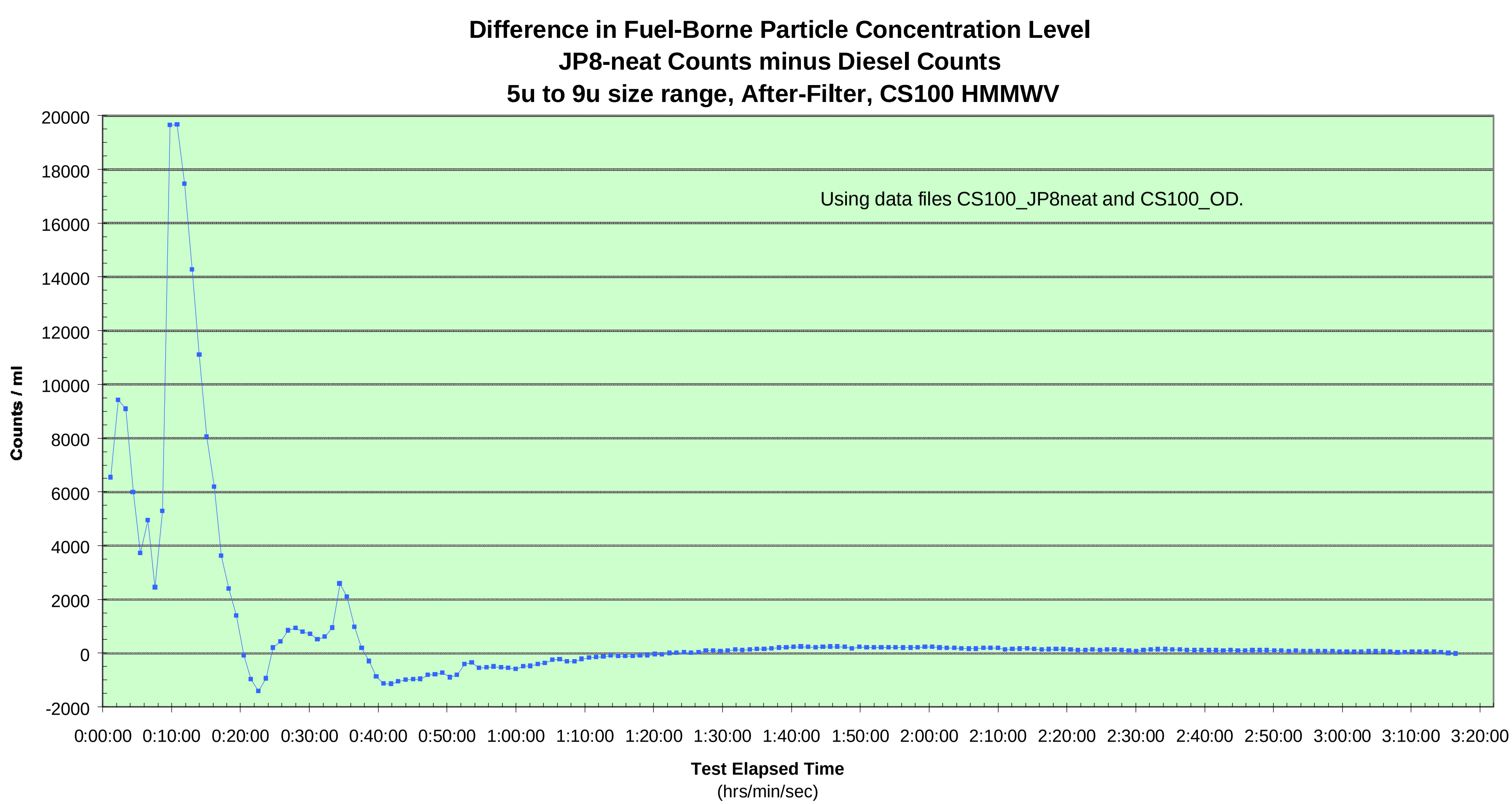
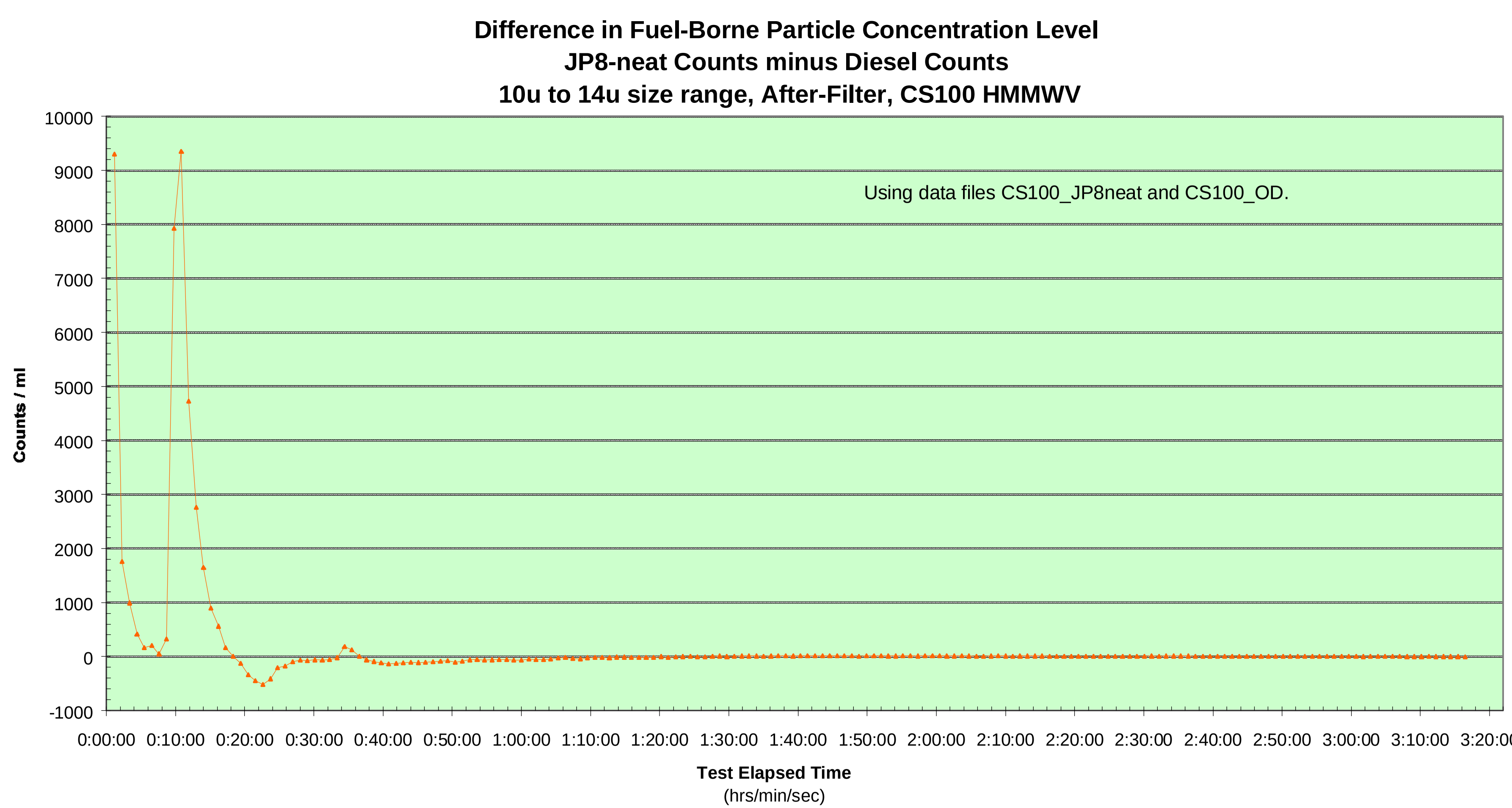

Difference in Fuel-Borne Particle Concentration Level
JP8-neat Counts minus Diesel Counts
5u to 9u size range, After-Filter, CS100 HMMWV
Using data files CS100_JP8neat and CS100_OD.
Counts / ml
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
-2000
0:00:00
0:10:00
0:20:00
0:30:00
0:40:00
0:50:00
1:00:00
1:10:00
1:20:00
1:30:00
1:40:00
1:50:00
2:00:00
2:10:00
2:20:00
2:30:00
2:40:00
2:50:00
3:00:00
3:10:00
3:20:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 3H



Difference in Fuel-Borne Particle Concentration Level
JP8-neat Counts minus Diesel Counts
10u to 14u size range, After-Filter, CS100 HMMWV
Using data files CS100_JP8neat and CS100_OD.
Counts / ml
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
-1000
0:00:00 0:10:00 0:20:00 0:30:00 0:40:00 0:50:00 1:00:00 1:10:00 1:20:00 1:30:00 1:40:00 1:50:00 2:00:00 2:10:00 2:20:00 2:30:00 2:40:00 2:50:00 3:00:00 3:10:00 3:20:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 3I

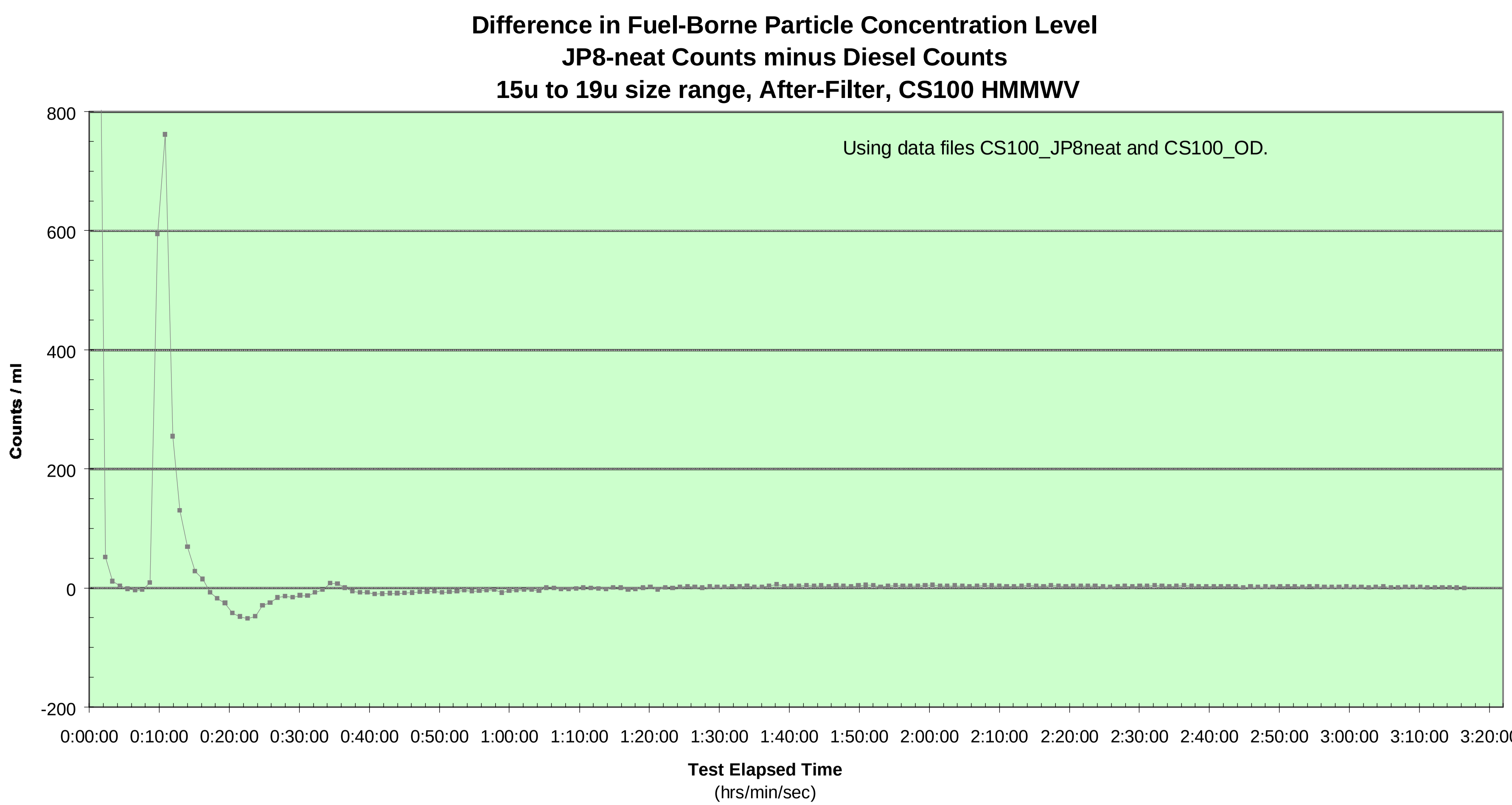
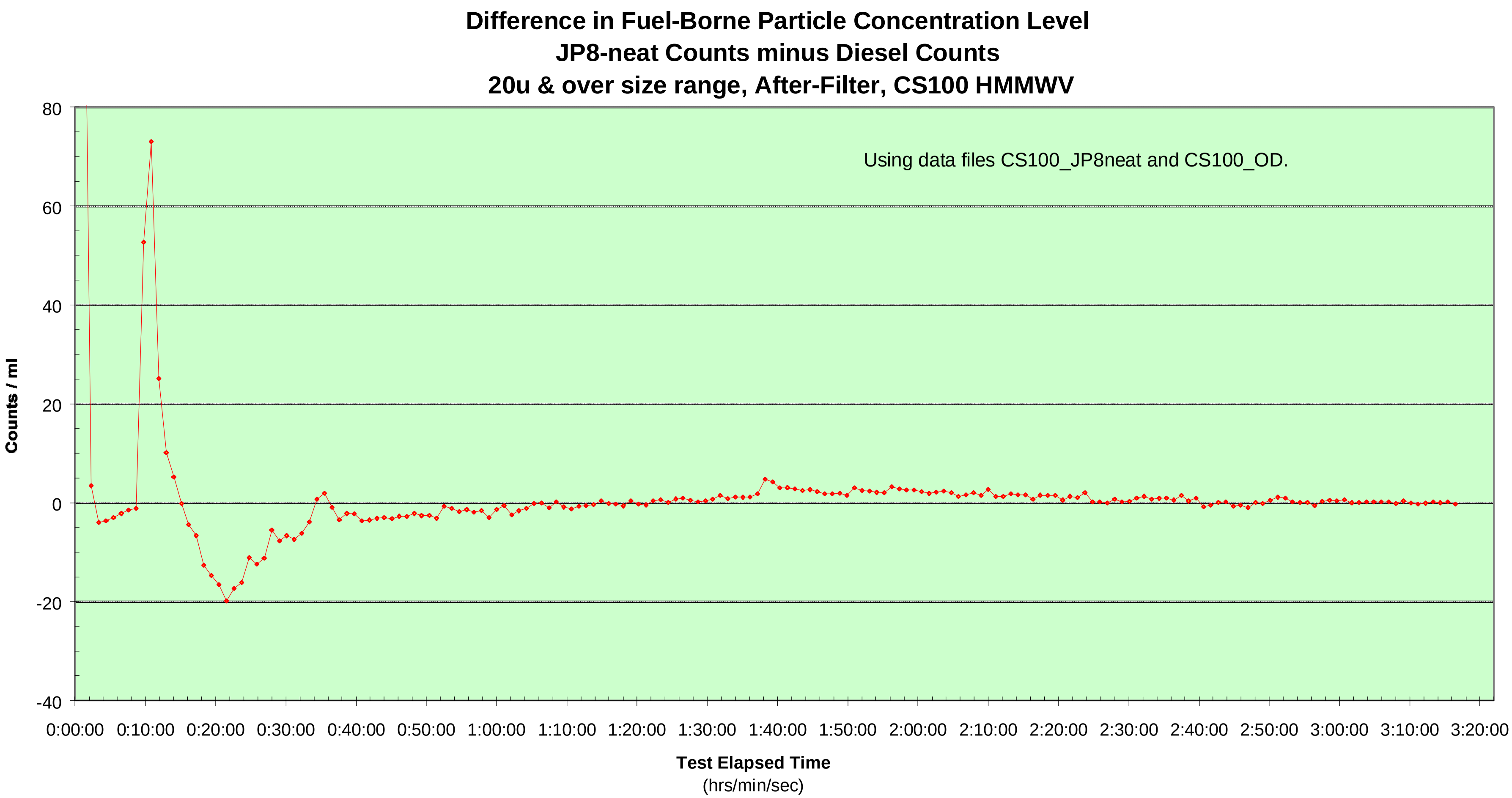

Difference in Fuel-Borne Particle Concentration Level
JP8-neat Counts minus Diesel Counts
15u to 19u size range, After-Filter, CS100 HMMWV
Using data files CS100_JP8neat and CS100_OD.
Counts / ml
800
600
400
200
0
-200
0:00:00
0:10:00
0:20:00
0:30:00
0:40:00
0:50:00
1:00:00
1:10:00
1:20:00
1:30:00
1:40:00
1:50:00
2:00:00
2:10:00
2:20:00
2:30:00
2:40:00
2:50:00
3:00:00
3:10:00
3:20:00
Test Elapsed Time
(hrs/min/sec)

FIGURE 3J


Difference in Fuel-Borne Particle Concentration Level
JP8-neat Counts minus Diesel Counts
20u & over size range, After-Filter, CS100 HMMWV
Using data files CS100_JP8neat and CS100_OD.
Counts / ml
80
60
40
20
0
-20
-40
0:00:00
0:10:00
0:20:00
0:30:00
0:40:00
0:50:00
1:00:00
1:10:00
1:20:00
1:30:00
1:40:00
1:50:00
2:00:00
2:10:00
2:20:00
2:30:00
2:40:00
2:50:00
3:00:00
3:10:00
3:20:00
Test Elapsed Time
(hrs/min/sec)

APPENDIX F

LABORATORY PARTICULATE AND WATER ANALYSIS DATA

Chemistry Lab Report of Fuel Analysis

WO # GLP-99-124

Project # 03-5137-707   JP-8+100 Vehicle Testing

Report date: 8-30-99

Sample ID	Total mL	K.F. Water Content ppm D-6304	Particulates mg/ L, D-5452
CS300-OD-BF	458	142	10.48
CS300-OD-AF	473	115	8.67
CS300-JP8+100-BF	581	147	1.72
CS300-JP8+100-AF	585	142	3.76
CS500-OD-BF	514	129	5.25
CS500-OD-AF	492	125	4.47
CS500-JP8+100-BF	636	238	10.38
CS500-JP8+100-AF	816	227	7.60
CS522-OD-BF	775	298	44.77
CS522-OD-AF	790	284	41.90
CS522-JP8+100-BF	820	242	4.51
CS522-JP8+100-AF	800	255	10.38
CS200-OD-BF	920	295	1.52
CS200-OD-AF	895	261	1.34
CS200-JP8+100-BF	910	304	1.10
CS200-JP8+100-AF	895	259	2.23
CS100-OD-BF	890	205	1.35
CS100-OD-AF	890	225	2.47
CS100JP8neat-BF	880	249	0.80
CS100JP8neat-AF	875	265	0.23